US009262673B2

(12) United States Patent
Shotton et al.

(10) **Patent No.: US 9,262,673 B2**

(45) **Date of Patent: Feb. 16, 2016**

(54) **HUMAN BODY POSE ESTIMATION**

(71) Applicant: **Microsoft Corporation**, Redmond, WA (US)

(72) Inventors: **Jamie Daniel Joseph Shotton**, Cambridge (GB); **Andrew William Fitzgibbon**, Cambridge (GB)

(73) Assignee: **Microsoft Technology Licensing, LLC**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 123 days.

(21) Appl. No.: **13/902,506**

(22) Filed: **May 24, 2013**

(65) **Prior Publication Data**

US 2013/0266182 A1 Oct. 10, 2013

Related U.S. Application Data

(63) Continuation of application No. 12/454,628, filed on May 20, 2009, now Pat. No. 8,503,720.

(60) Provisional application No. 61/174,878, filed on May 1, 2009.

(51) **Int. Cl.**
G06K 9/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G06K 9/00335*** (2013.01); ***G06K 9/00369*** (2013.01)

(58) **Field of Classification Search**
CPC G06K 9/00369; G06K 9/00335; G06K 9/00342; A63F 13/06; A63F 13/10; A63F 2300/1043; A63F 2300/1081; A63F 2300/1087; A63F 2300/6045; H04N 7/183; G03B 17/54; G03B 21/14; G03B 35/00; G03B 35/08; G06F 3/005; G06F 3/011; G06F 3/017
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,627,620	A	12/1986	Yang
4,630,910	A	12/1986	Ross et al.
4,645,458	A	2/1987	Williams
4,695,953	A	9/1987	Blair et al.
4,702,475	A	10/1987	Elstein et al.
4,711,543	A	12/1987	Blair et al.
4,751,642	A	6/1988	Silva et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN	101254344	B	6/2010
EP	0583061	A2	2/1994

(Continued)

OTHER PUBLICATIONS

"Virtual High Anxiety", Tech Update, Aug. 1995, pp. 22.

(Continued)

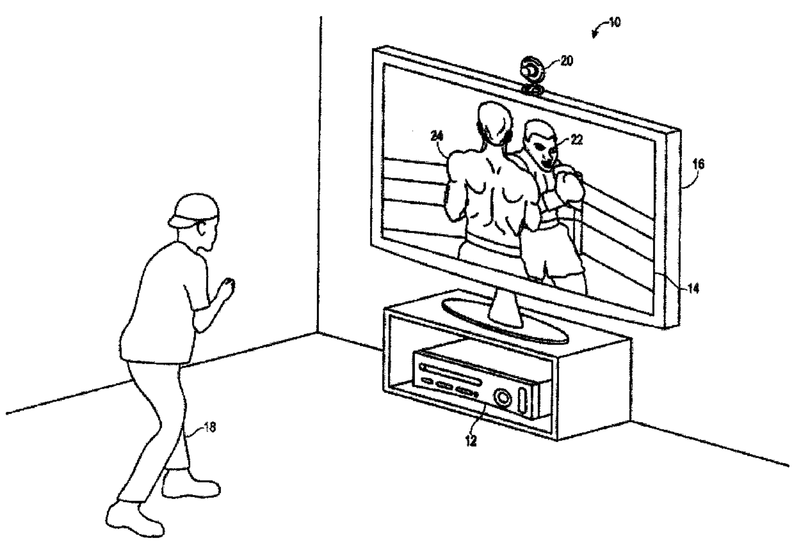
Primary Examiner — Tom Y Lu

(74) *Attorney, Agent, or Firm* — Gregg Wisdom; Judy Yee; Micky Minhas

(57) **ABSTRACT**

Techniques for human body pose estimation are disclosed herein. Depth map images from a depth camera may be processed to calculate a probability that each pixel of the depth map is associated with one or more segments or body parts of a body. Body parts may then be constructed of the pixels and processed to define joints or nodes of those body parts. The nodes or joints may be provided to a system which may construct a model of the body from the various nodes or joints.

20 Claims, 15 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,796,997	A	1/1989	Svetkoff et al.
4,809,065	A	2/1989	Harris et al.
4,817,950	A	4/1989	Goo
4,843,568	A	6/1989	Krueger et al.
4,893,183	A	1/1990	Nayar
4,901,362	A	2/1990	Terzian
4,925,189	A	5/1990	Braeunig
5,101,444	A	3/1992	Wilson et al.
5,148,154	A	9/1992	MacKay et al.
5,184,295	A	2/1993	Mann
5,229,754	A	7/1993	Aoki et al.
5,229,756	A	7/1993	Kosugi et al.
5,239,463	A	8/1993	Blair et al.
5,239,464	A	8/1993	Blair et al.
5,288,078	A	2/1994	Capper et al.
5,295,491	A	3/1994	Gevins
5,320,538	A	6/1994	Baum
5,347,306	A	9/1994	Nitta
5,385,519	A	1/1995	Hsu et al.
5,405,152	A	4/1995	Katanics et al.
5,417,210	A	5/1995	Funda et al.
5,423,554	A	6/1995	Davis
5,454,043	A	9/1995	Freeman
5,469,740	A	11/1995	French et al.
5,495,576	A	2/1996	Ritchey
5,516,105	A	5/1996	Eisenbrey et al.
5,524,637	A	6/1996	Erickson et al.
5,534,917	A	7/1996	MacDougall
5,563,988	A	10/1996	Maes et al.
5,577,981	A	11/1996	Jarvik
5,580,249	A	12/1996	Jacobsen et al.
5,594,469	A	1/1997	Freeman et al.
5,597,309	A	1/1997	Riess
5,616,078	A	4/1997	Oh
5,617,312	A	4/1997	Iura et al.
5,638,300	A	6/1997	Johnson
5,641,288	A	6/1997	Zaenglein
5,682,196	A	10/1997	Freeman
5,682,229	A	10/1997	Wangler
5,690,582	A	11/1997	Ulrich et al.
5,703,367	A	12/1997	Hashimoto et al.
5,704,837	A	1/1998	Iwasaki et al.
5,715,834	A	2/1998	Bergamasco et al.
5,875,108	A	2/1999	Hoffberg et al.
5,877,803	A	3/1999	Wee et al.
5,913,727	A	6/1999	Ahdoot
5,930,392	A	7/1999	Ho
5,933,125	A	8/1999	Fernie
5,980,256	A	11/1999	Carmein
5,989,157	A	11/1999	Walton
5,995,649	A	11/1999	Marugame
6,005,548	A	12/1999	Latypov et al.
6,009,210	A	12/1999	Kang
6,054,991	A	4/2000	Crane et al.
6,057,909	A	5/2000	Yahav et al.
6,066,075	A	5/2000	Poulton
6,072,494	A	6/2000	Nguyen
6,073,489	A	6/2000	French et al.
6,077,201	A	6/2000	Cheng et al.
6,098,458	A	8/2000	French et al.
6,100,517	A	8/2000	Yahav et al.
6,100,896	A	8/2000	Strohecker et al.
6,101,289	A	8/2000	Kellner
6,128,003	A	10/2000	Smith et al.
6,130,677	A	10/2000	Kunz
6,141,463	A	10/2000	Covell et al.
6,147,678	A	11/2000	Kumar et al.
6,152,856	A	11/2000	Studor et al.
6,159,100	A	12/2000	Smith
6,173,066	B1	1/2001	Peurach et al.
6,181,343	B1	1/2001	Lyons
6,188,777	B1	2/2001	Darrell et al.
6,215,890	B1	4/2001	Matsuo et al.
6,215,898	B1	4/2001	Woodfill et al.
6,226,396	B1	5/2001	Marugame
6,229,913	B1	5/2001	Nayar et al.
6,256,033	B1	7/2001	Nguyen
6,256,400	B1	7/2001	Takata et al.
6,283,860	B1	9/2001	Lyons et al.
6,289,112	B1	9/2001	Jain et al.
6,299,308	B1	10/2001	Voronka et al.
6,308,565	B1	10/2001	French et al.
6,316,934	B1	11/2001	Amorai-Moriya et al.
6,363,160	B1	3/2002	Bradski et al.
6,384,819	B1	5/2002	Hunter
6,411,744	B1	6/2002	Edwards
6,430,997	B1	8/2002	French et al.
6,476,834	B1	11/2002	Doval et al.
6,496,598	B1	12/2002	Harman
6,498,628	B2	12/2002	Iwamura
6,502,515	B2	1/2003	Burckhardt et al.
6,503,195	B1	1/2003	Keller et al.
6,512,838	B1	1/2003	Rafii et al.
6,539,931	B2	4/2003	Trajkovic et al.
6,570,555	B1	5/2003	Prevost et al.
6,633,294	B1	10/2003	Rosenthal et al.
6,640,202	B1	10/2003	Dietz et al.
6,661,918	B1	12/2003	Gordon et al.
6,674,877	B1	1/2004	Jojic et al.
6,681,031	B2	1/2004	Cohen et al.
6,714,665	B1	3/2004	Hanna et al.
6,731,799	B1	5/2004	Sun et al.
6,738,066	B1	5/2004	Nguyen
6,741,756	B1	5/2004	Toyama
6,765,726	B2	7/2004	French et al.
6,771,277	B2	8/2004	Ohba
6,788,809	B1	9/2004	Grzeszczuk et al.
6,801,637	B2	10/2004	Voronka et al.
6,873,723	B1	3/2005	Aucsmith et al.
6,876,496	B2	4/2005	French et al.
6,879,709	B2	4/2005	Tian
6,937,742	B2	8/2005	Roberts et al.
6,950,534	B2	9/2005	Cohen et al.
7,003,134	B1	2/2006	Covell et al.
7,006,236	B2	2/2006	Tomasi et al.
7,036,094	B1	4/2006	Cohen et al.
7,038,855	B2	5/2006	French et al.
7,039,676	B1	5/2006	Day et al.
7,042,440	B2	5/2006	Pryor et al.
7,050,177	B2	5/2006	Tomasi et al.
7,050,606	B2	5/2006	Paul et al.
7,058,204	B2	6/2006	Hildreth et al.
7,060,957	B2	6/2006	Lange et al.
7,113,918	B1	9/2006	Ahmad et al.
7,121,946	B2	10/2006	Paul et al.
7,151,530	B2	12/2006	Roeber et al.
7,170,492	B2	1/2007	Bell
7,184,048	B2	2/2007	Hunter
7,202,898	B1	4/2007	Braun et al.
7,222,078	B2	5/2007	Abelow
7,224,384	B1	5/2007	Iddan et al.
7,227,526	B2	6/2007	Hildreth et al.
7,259,747	B2	8/2007	Bell
7,293,356	B2	11/2007	Sohn et al.
7,308,112	B2	12/2007	Fujimura et al.
7,310,431	B2	12/2007	Gokturk et al.
7,317,836	B2	1/2008	Fujimura et al.
7,340,077	B2	3/2008	Gokturk et al.
7,348,963	B2	3/2008	Bell
7,359,121	B2	4/2008	French et al.
7,367,887	B2	5/2008	Watabe et al.
7,379,563	B2	5/2008	Shamaie
7,379,566	B2	5/2008	Hildreth
7,389,591	B2	6/2008	Jaiswal et al.
7,412,077	B2	8/2008	Li et al.
7,421,093	B2	9/2008	Hildreth et al.
7,430,312	B2	9/2008	Gu
7,436,496	B2	10/2008	Kawahito
7,450,736	B2	11/2008	Yang et al.
7,452,275	B2	11/2008	Kuraishi
7,460,690	B2	12/2008	Cohen et al.
7,489,812	B2	2/2009	Fox et al.
7,536,032	B2	5/2009	Bell
7,555,142	B2	6/2009	Hildreth et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,560,701	B2	7/2009	Oggier et al.	
7,570,805	B2	8/2009	Gu	
7,574,020	B2	8/2009	Shamaie	
7,576,727	B2	8/2009	Bell	
7,590,262	B2	9/2009	Fujimura et al.	
7,593,552	B2	9/2009	Higaki et al.	
7,598,942	B2	10/2009	Underkoffler et al.	
7,607,509	B2	10/2009	Schmiz et al.	
7,620,202	B2	11/2009	Fujimura et al.	
7,668,340	B2	2/2010	Cohen et al.	
7,680,298	B2	3/2010	Roberts et al.	
7,683,954	B2	3/2010	Ichikawa et al.	
7,684,592	B2	3/2010	Paul et al.	
7,701,439	B2	4/2010	Hillis et al.	
7,702,130	B2	4/2010	Im et al.	
7,704,135	B2	4/2010	Harrison, Jr.	
7,710,391	B2	5/2010	Bell et al.	
7,729,530	B2	6/2010	Antonov et al.	
7,746,345	B2	6/2010	Hunter	
7,760,182	B2	7/2010	Ahmad et al.	
7,809,167	B2	10/2010	Bell	
7,834,846	B1	11/2010	Bell	
7,852,262	B2	12/2010	Namineni et al.	
RE42,256	E	3/2011	Edwards	
7,898,522	B2	3/2011	Hildreth et al.	
8,035,612	B2	10/2011	Bell et al.	
8,035,614	B2	10/2011	Bell et al.	
8,035,624	B2	10/2011	Bell et al.	
8,072,470	B2	12/2011	Marks	
8,290,249	B2 *	10/2012	Mathe et al.	382/154
2004/0207597	A1	10/2004	Marks	
2005/0059488	A1	3/2005	Larsen et al.	
2006/0188144	A1	8/2006	Sasaki et al.	
2006/0239558	A1	10/2006	Rafii et al.	
2007/0013718	A1	1/2007	Ohba	
2007/0060336	A1	3/2007	Marks et al.	
2007/0098222	A1	5/2007	Porter et al.	
2007/0216894	A1	9/2007	Garcia et al.	
2007/0217676	A1	9/2007	Grauman	
2007/0260984	A1	11/2007	Marks et al.	
2007/0279485	A1	12/2007	Ohba et al.	
2007/0283296	A1	12/2007	Nilsson	
2007/0298882	A1	12/2007	Marks et al.	
2008/0001951	A1	1/2008	Marks et al.	
2008/0026838	A1	1/2008	Dunstan et al.	
2008/0062257	A1	3/2008	Corson	
2008/0100620	A1	5/2008	Nagai et al.	
2008/0126937	A1	5/2008	Pachet	
2008/0134102	A1	6/2008	Movold et al.	
2008/0137956	A1	6/2008	Yang	
2008/0152191	A1	6/2008	Fujimura et al.	
2008/0152218	A1	6/2008	Okada	
2008/0215972	A1	9/2008	Zalewski et al.	
2008/0215973	A1	9/2008	Zalewski et al.	
2009/0141933	A1	6/2009	Wagg	
2009/0167679	A1	7/2009	Klier et al.	
2009/0221368	A1	9/2009	Yen et al.	
2010/0093435	A1	4/2010	Glaser et al.	
2010/0197393	A1 *	8/2010	Geiss	463/30
2012/0194516	A1	8/2012	Newcombe et al.	
2012/0196679	A1	8/2012	Newcombe et al.	

FOREIGN PATENT DOCUMENTS

JP	08044490	A	2/1996
WO	WO 93/10708	A1	6/1993
WO	WO 97/17598	A1	5/1997
WO	WO 99/15863	A1	4/1999
WO	WO 99/44698	A1	9/1999
WO	WO 01/59975	A3	1/2002
WO	WO 02/082249	A2	10/2002
WO	WO 03/001722	A3	3/2003
WO	WO 03/046706	A1	6/2003
WO	WO 03/073359	A3	11/2003
WO	WO 03/054683	A3	12/2003
WO	WO 03/071410	A3	3/2004
WO	WO 2009/059065	A1	5/2009

OTHER PUBLICATIONS

Aggarwal et al., "Human Motion Analysis: A Review", IEEE Non-rigid and Articulated Motion Workshop, 1997, University of Texas at Austin, Austin, TX.

Azarbayejani et al., "Visually Controlled Graphics", Jun. 1993, vol. 15, No. 6, IEEE Transactions on Pattern Analysis and Machine Intelligence.

Breen et al., "Interactive Occlusion and Collusion of Real and Virtual Objects in Augmented Reality", Technical Report ECRC-95-02, 1995, European Computer-Industry Research Center GmbH, Munich, Germany.

Brogan et al., "Dynamically Simulated Characters in Virtual Environments", Sep./Oct. 1998, pp. 2-13, vol. 18, Issue 5, IEEE Computer Graphics and Applications.

Fisher et al., "Virtual Environment Display System", ACM Workshop on Interactive 3D Graphics, Oct. 1986, Chapel Hill, NC.

Freeman et al., "Television Control by Hand Gestures", Dec. 1994, Mitsubishi Electric Research Laboratories, TR94-24, Caimbridge, MA.

Granieri et al., "Simulating Humans in VR", The British Computer Society, Oct. 1994, Academic Press.

Hasegawa et al., "Human-Scale Haptic Interaction with a Reactive Virtual Human in a Real-Time Physics Simulator", Jul. 2006, vol. 4, No. 3, Article 6C, ACM Computers in Entertainment, New York, NY.

He, "Generation of Human Body Models", Apr. 2005, University of Auckland, New Zealand.

Hongo et al., "Focus of Attention for Face and Hand Gesture Recognition Using Multiple Cameras", Mar. 2000, pp. 156-161, 4th IEEE International Conference on Automatic Face and Gesture Recognition, Grenoble, France.

Isard et al., "Condensation—Conditional Density Propagation for Visual Tracking", 1998, pp. 5-28, International Journal of Computer Vision 29(1), Netherlands.

Kanade et al., "A Stereo Machine for Video-rate Dense Depth Mapping and Its New Applications", IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 1996, pp. 196-202,The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA.

Kohler, "Special Topics of Gesture Recognition Applied in Intelligent Home Environments", In Proceedings of the Gesture Workshop, 1998, pp. 285-296, Germany.

Kohler, "Technical Details and Ergonomical Aspects of Gesture Recognition applied in Intelligent Home Environments", 1997, Germany.

Kohler, "Vision Based Remote Control in Intelligent Home Environments", University of Erlangen-Nuremberg/Germany, 1996, pp. 147-154, Germany.

Livingston, "Vision-based Tracking with Dynamic Structured Light for Video See-through Augmented Reality", 1998, University of North Carolina at Chapel Hill, North Carolina, USA.

Miyagawa et al., "CCD-Based Range Finding Sensor", Oct. 1997, pp. 1648-1652, vol. 44 No. 10, IEEE Transactions on Electron Devices.

Pavlovic et al., "Visual Interpretation of Hand Gestures for Human-Computer Interaction: A Review", Jul. 1997, pp. 677-695, vol. 19, No. 7, IEEE Transactions on Pattern Analysis and Machine Intelligence.

Rosenhahn et al., "Automatic Human Model Generation", 2005, pp. 41-48, University of Auckland (CITR), New Zealand.

Shao et al., "An Open System Architecture for a Multimedia and Multimodal User Interface", Aug. 24, 1998, Japanese Society for Rehabilitation of Persons with Disabilities (JSRPD), Japan.

Sheridan et al., "Virtual Reality Check", Technology Review, Oct. 1993, pp. 22-28, vol. 96, No. 7.

Stevens, "Flights into Virtual Reality Treating Real World Disorders", The Washington Post, Mar. 27, 1995, Science Psychology, 2 pages.

Wren et al., "Pfinder: Real-Time Tracking of the Human Body", MIT Media Laboratory Perceptual Computing Section Technical Report

(56) **References Cited**

OTHER PUBLICATIONS

No. 353, Jul. 1997, vol. 19, No. 7, pp. 780-785, IEEE Transactions on Pattern Analysis and Machine Intelligence, Caimbridge, MA.
Zhao, "Dressed Human Modeling, Detection, and Parts Localization", 2001, The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA.
Qian et al., "A Gesture-Driven Multimodal Interactive Dance System", Jun. 2004, pp. 1579-1582, IEEE International Conference on Multimedia and Expo (ICME), Taipei, Taiwan.
Thayananthan et al., "Pose Estimation and Tracking Using Multivariate Regression," Elsevier, http://svr-www.eng.cam.ac.uk/~bdrs2/papers/thayananthan_prl08.pdf, Oct. 8, 2007, pp. 1-15.
Laxton, B., "Monocular Human Pose Estimation," University of California, San Diego, http://vision.ucsd.edu/~blaxton/pagePapers/laxton_researchExam2007.pdf, downloaded Jun. 26, 2009, 16 pages.
Navaratnam et al., "Hierarchical Part-Based Human Body Pose Estimation," http://mi.eng.cam.ac.uk/reports/svr-ftp/navaratnam_hierarchical.pdf, downloaded Jun. 1, 2009, pp. 1-10.
Kanaujia et al., "Semi-Supervised Hierarchical Models for 3D Human Pose Reconstruction," Rutgers University and TTI-Chicago, http://www.cs.toronto.edu/~crismin/PAPERS/Smi-cvpr07.pdf, downloaded Jun. 1, 2009, pp. 1-8.
Zhong, Y., "A Weighting Scheme for Content-Based Image Retrieval," University of Wollongong, http://www.library.uow.edu.au/adt-NWU/uploads/approved/adt-NWU20080116.091123/public/01Front.pdf, 2007, 13 pages.
Agarwal et al., "Learning Methods for Recovering 3D Human Pose from Monocular Images," Technical Report 5333, INRIA Rhone-Alpes, Oct. 2004, pp. 1-25.
Shivappa et al., "Person Tracking with Audio-Visual Cues Using Iterative Decoding Framework", IEEE Fifth International Conference on Advanced Video and Signal Based Surveillance, AVSS '08, Santa Fe, NM, Sep. 1-3, 2008, 260-267.
"International Search Report & Written Opinion for PCT Patent Application No. PCT/US2014/016749", Mailed Date: May 12, 2014, Filed Date: Feb. 18, 2014, 8 Pages.
Daniel, et al., "Pose Tracking from Natural Features on Mobile Phones", In IEEE/ACM International Symposium on Mixed and Augmented Reality, Sep. 15, 2008, pp. 125-134.
Breiman, Leo, "Random Forests", In Machine Learning, vol. 45, Issue 1, Oct. 2001, pp. 5-32.
Veas, et al., "Creating Meaningful Environment Models for Augmented Reality", In IEEE Virtual Reality Conference, Mar. 8, 2008, pp. 295-296.

* cited by examiner

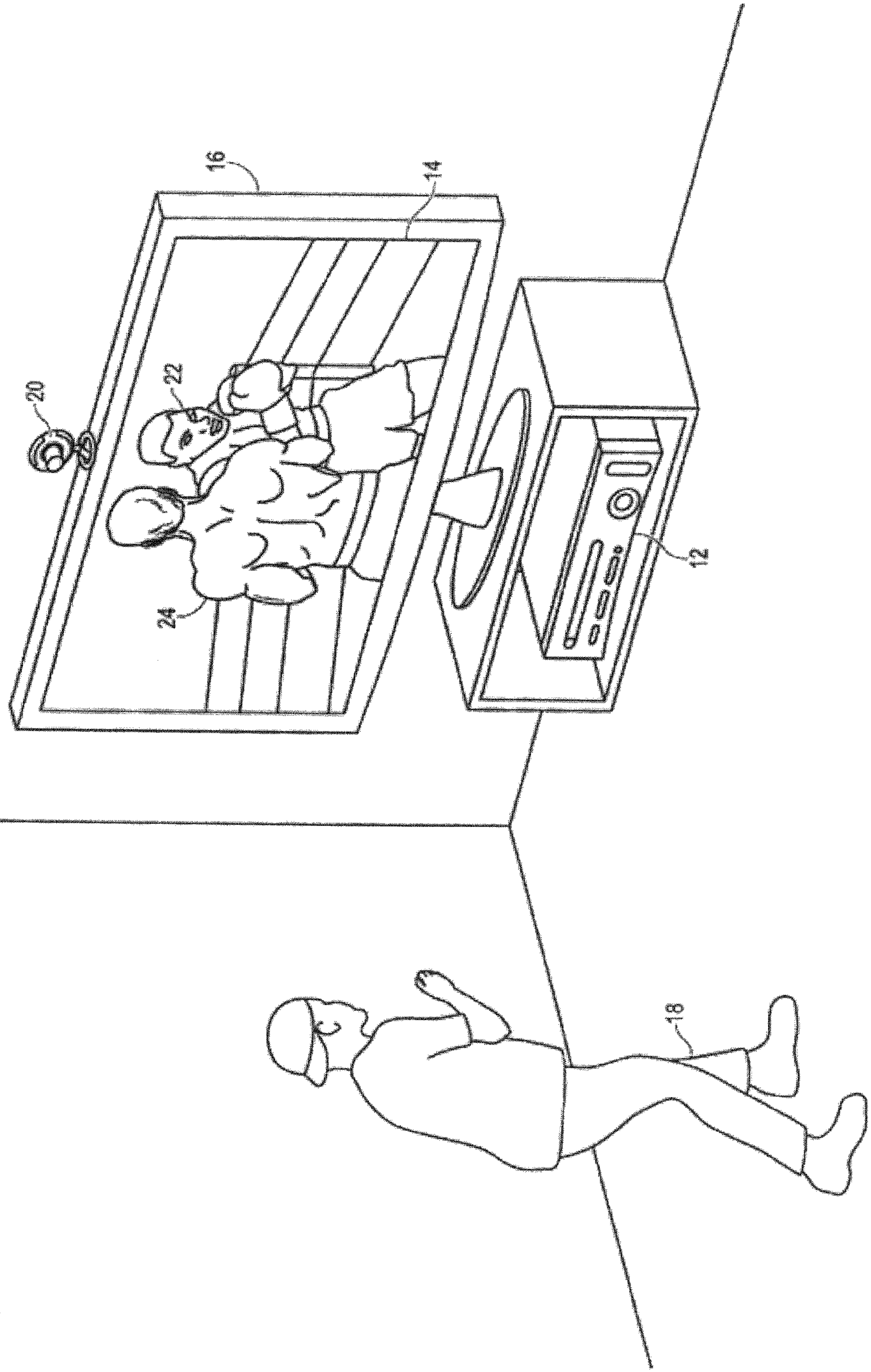


Fig. 1A

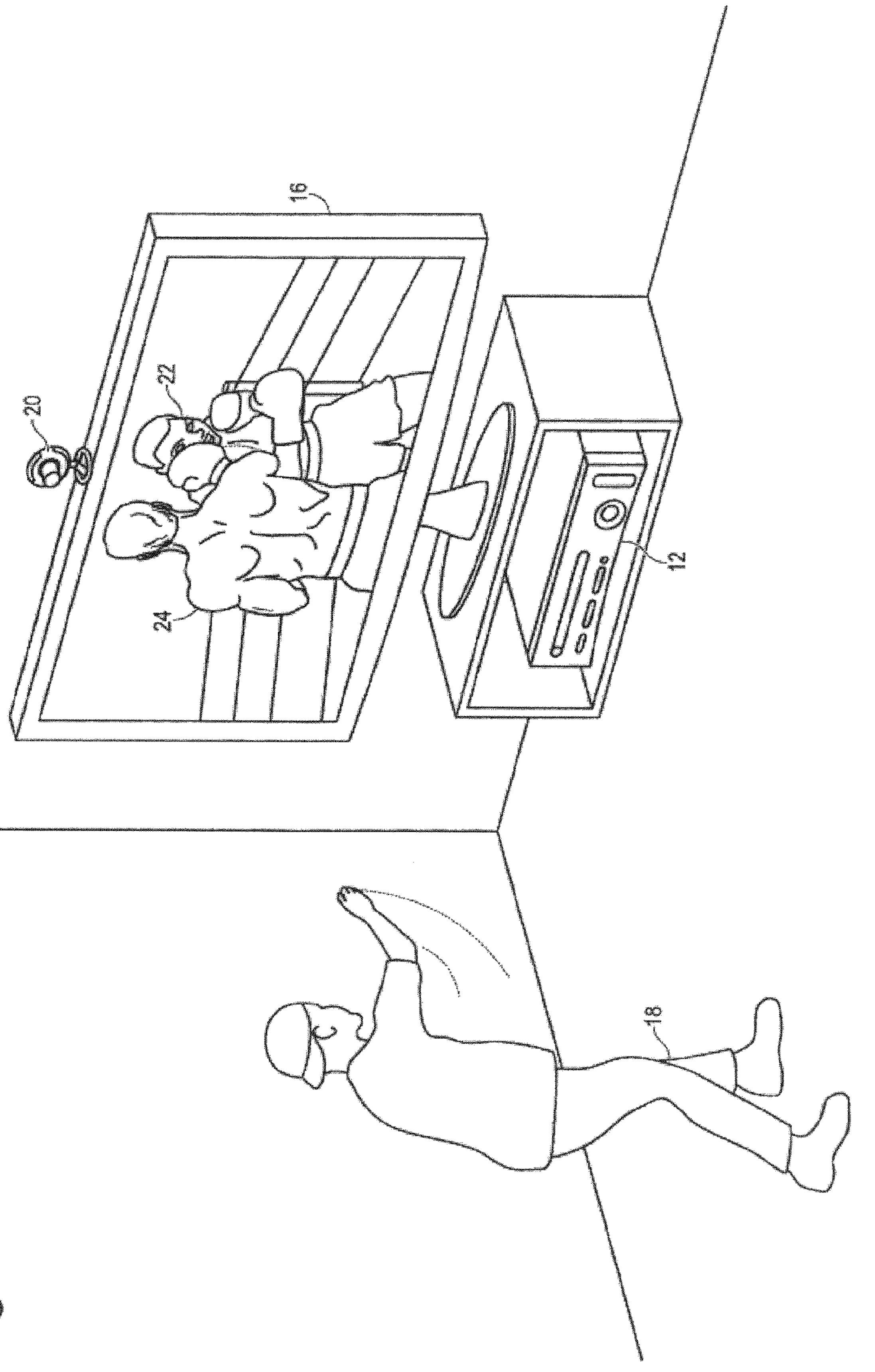


Fig. 1B

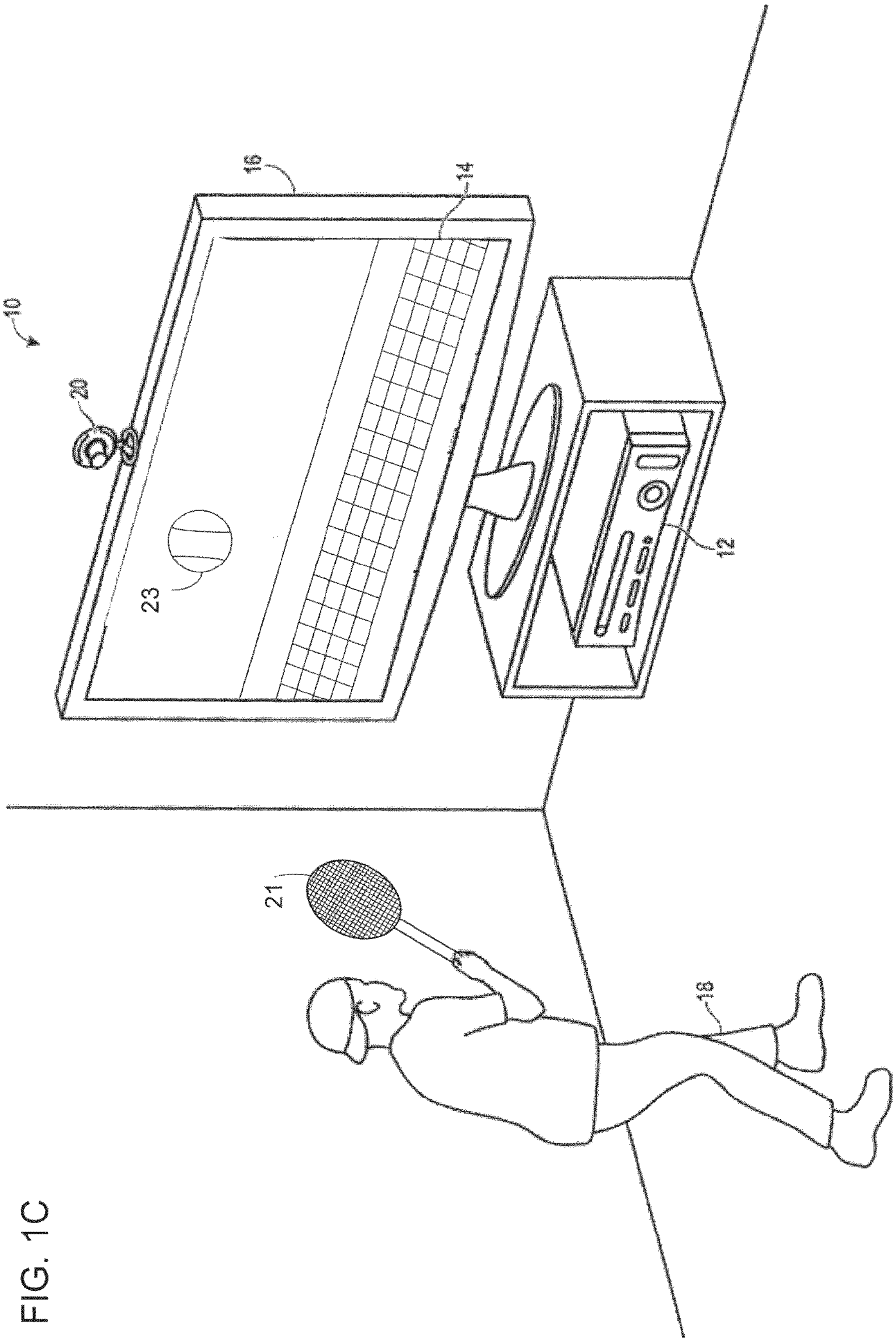
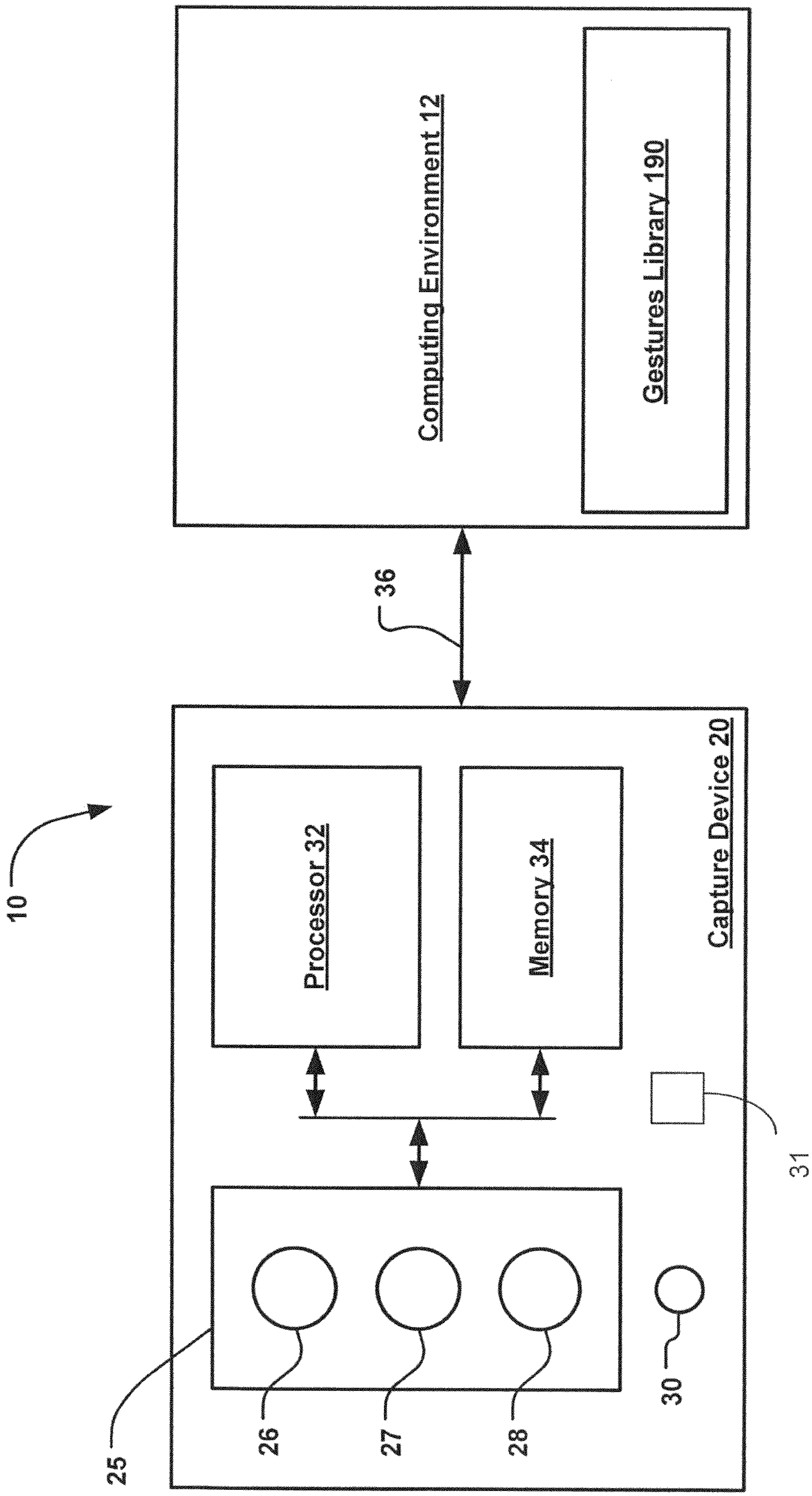


FIG. 1C



Computing Environment 12
Gestures Library 190
36
10
Processor 32
Memory 34
Capture Device 20
31
25
26
27
28
30

FIG. 2

FIG. 3

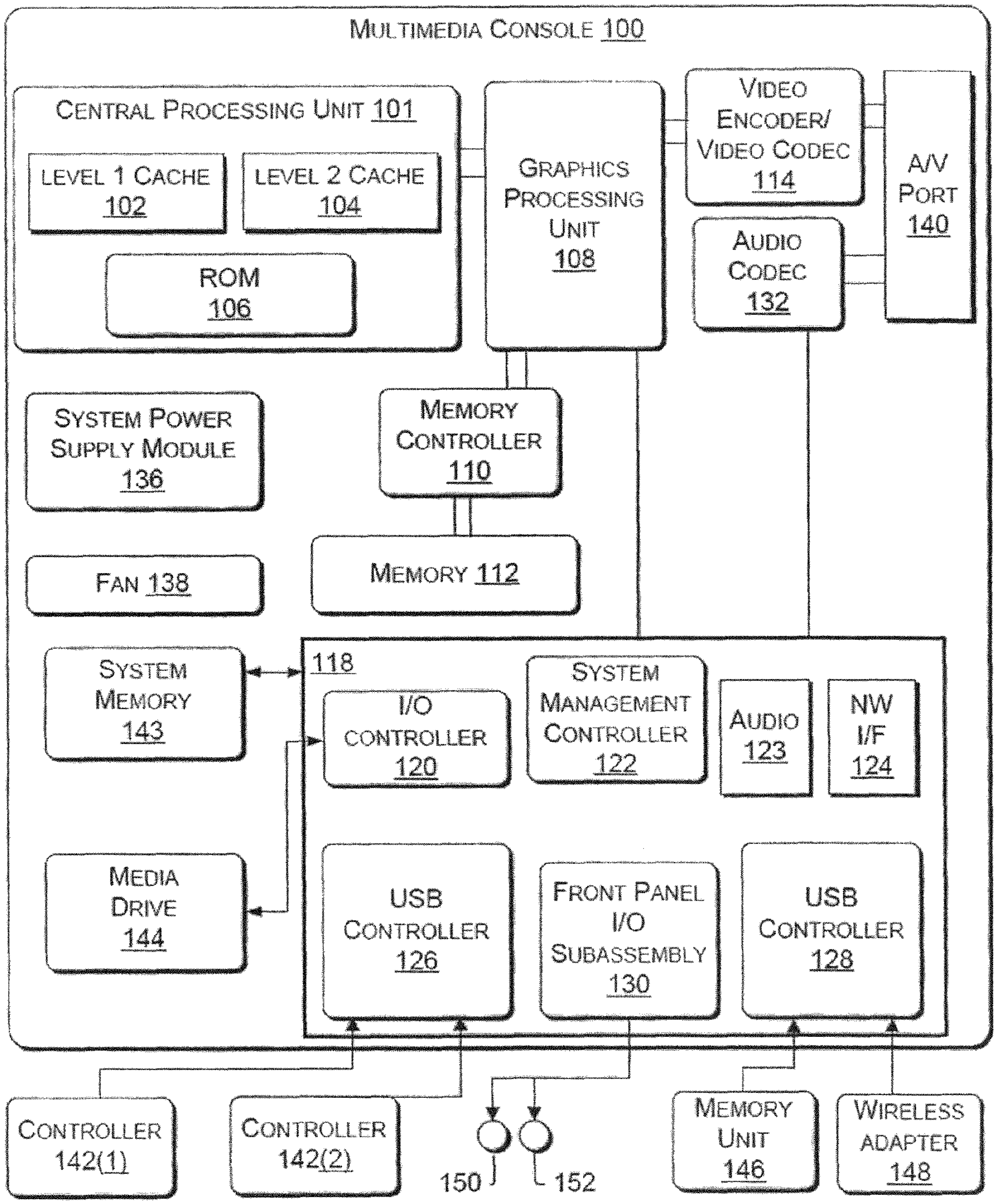
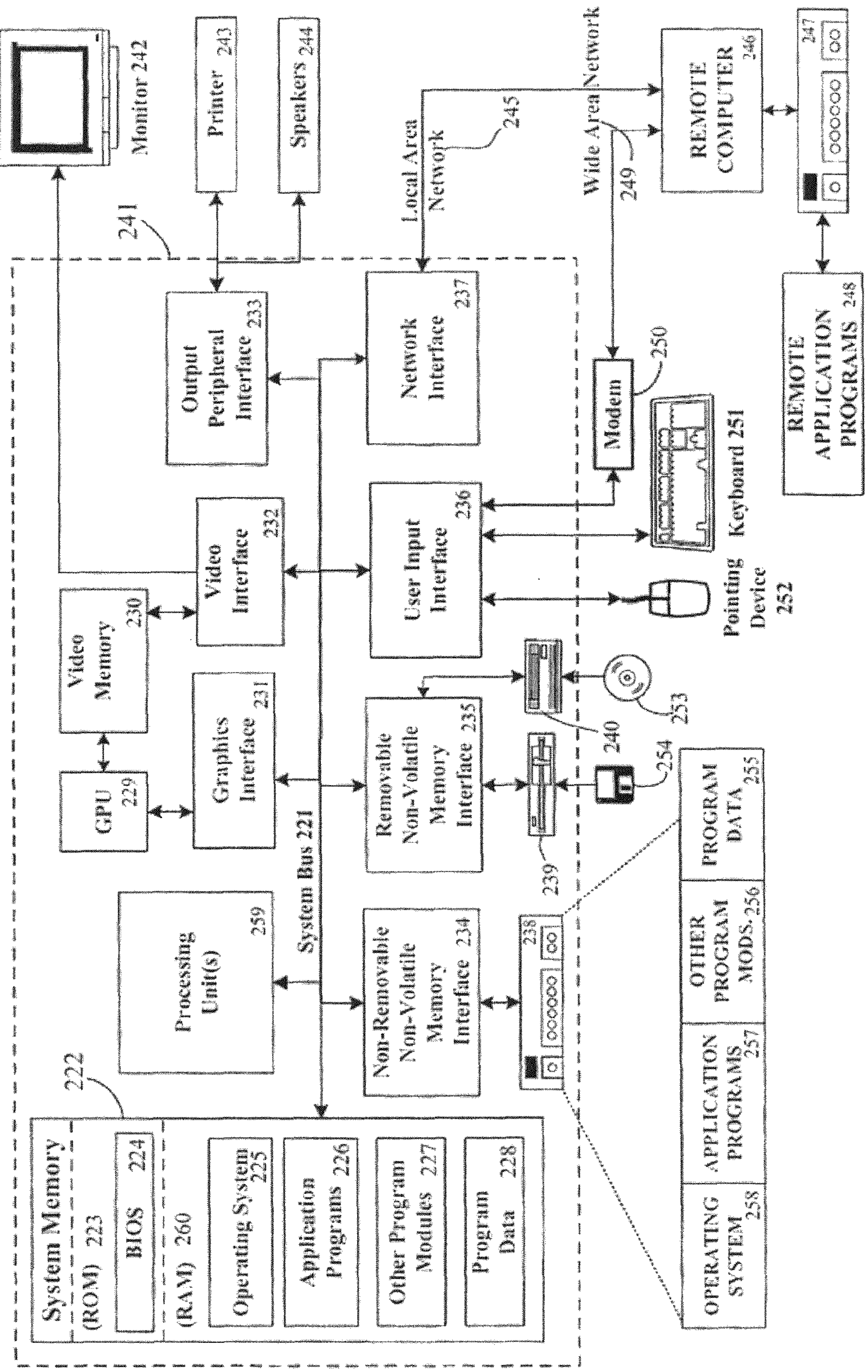

MULTIMEDIA CONSOLE 100
CENTRAL PROCESSING UNIT 101
LEVEL 1 CACHE 102
LEVEL 2 CACHE 104
ROM 106
GRAPHICS PROCESSING UNIT 108
VIDEO ENCODER/ VIDEO CODEC 114
A/V PORT 140
AUDIO CODEC 132
SYSTEM POWER SUPPLY MODULE 136
MEMORY CONTROLLER 110
FAN 138
MEMORY 112
SYSTEM MEMORY 143
118
I/O CONTROLLER 120
SYSTEM MANAGEMENT CONTROLLER 122
AUDIO 123
NW I/F 124
MEDIA DRIVE 144
USB CONTROLLER 126
FRONT PANEL I/O SUBASSEMBLY 130
USB CONTROLLER 128
CONTROLLER 142(1)
CONTROLLER 142(2)
150
152
MEMORY UNIT 146
WIRELESS ADAPTER 148

FIG. 4

FIG. 5


Monitor 242
Printer 243
Speakers 244
241
Local Area Network
245
Wide Area Network
249
REMOTE COMPUTER 246
247
REMOTE APPLICATION PROGRAMS 248
Output Peripheral Interface 233
Network Interface 237
Modem
250
Keyboard 251
Video Interface 232
User Input Interface 236
Pointing Device 252
Video Memory 230
GPU 229
Graphics Interface 231
Removable Non-Volatile Memory Interface 235
240
253
254
239
System Bus 221
Processing Unit(s) 259
Non-Removable Non-Volatile Memory Interface 234
238
PROGRAM DATA 255
OTHER PROGRAM MODS. 256
APPLICATION PROGRAMS 257
OPERATING SYSTEM 258
222
System Memory
(ROM) 223
BIOS 224
(RAM) 260
Operating System 225
Application Programs 226
Other Program Modules 227
Program Data 228

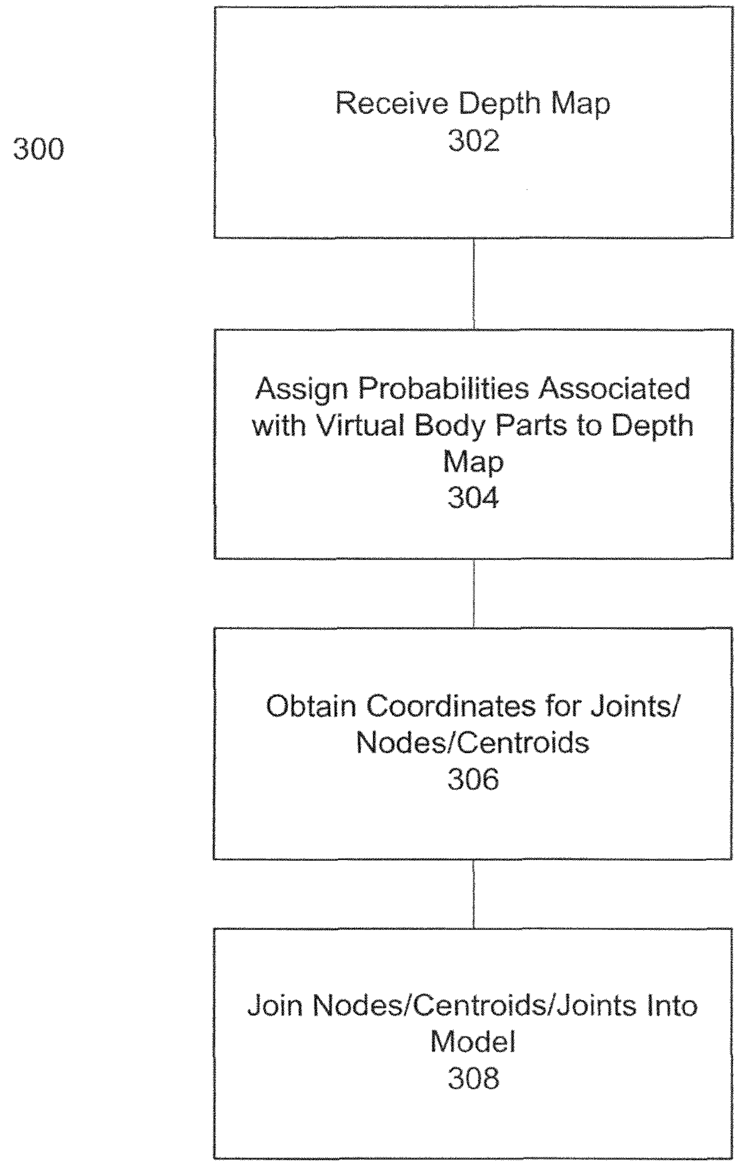

300
Receive Depth Map
302
Assign Probabilities Associated with Virtual Body Parts to Depth Map
304
Obtain Coordinates for Joints/ Nodes/Centroids
306
Join Nodes/Centroids/Joints Into Model
308

FIG. 6

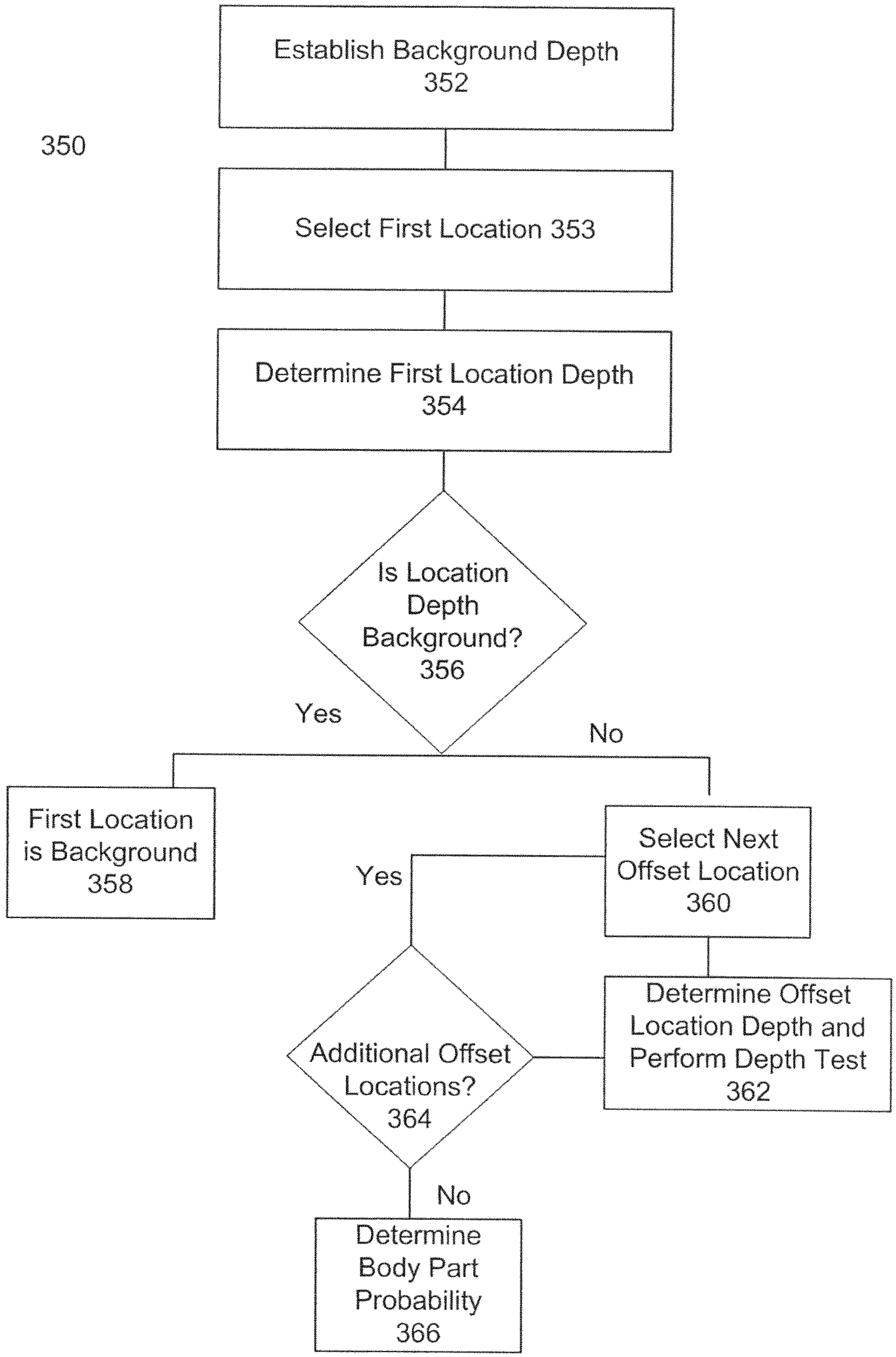

Establish Background Depth 352
350
Select First Location 353
Determine First Location Depth 354
Is Location Depth Background? 356
Yes
No
First Location is Background 358
Select Next Offset Location 360
Yes
Determine Offset Location Depth and Perform Depth Test 362
Additional Offset Locations? 364
No
Determine Body Part Probability 366

FIG. 7

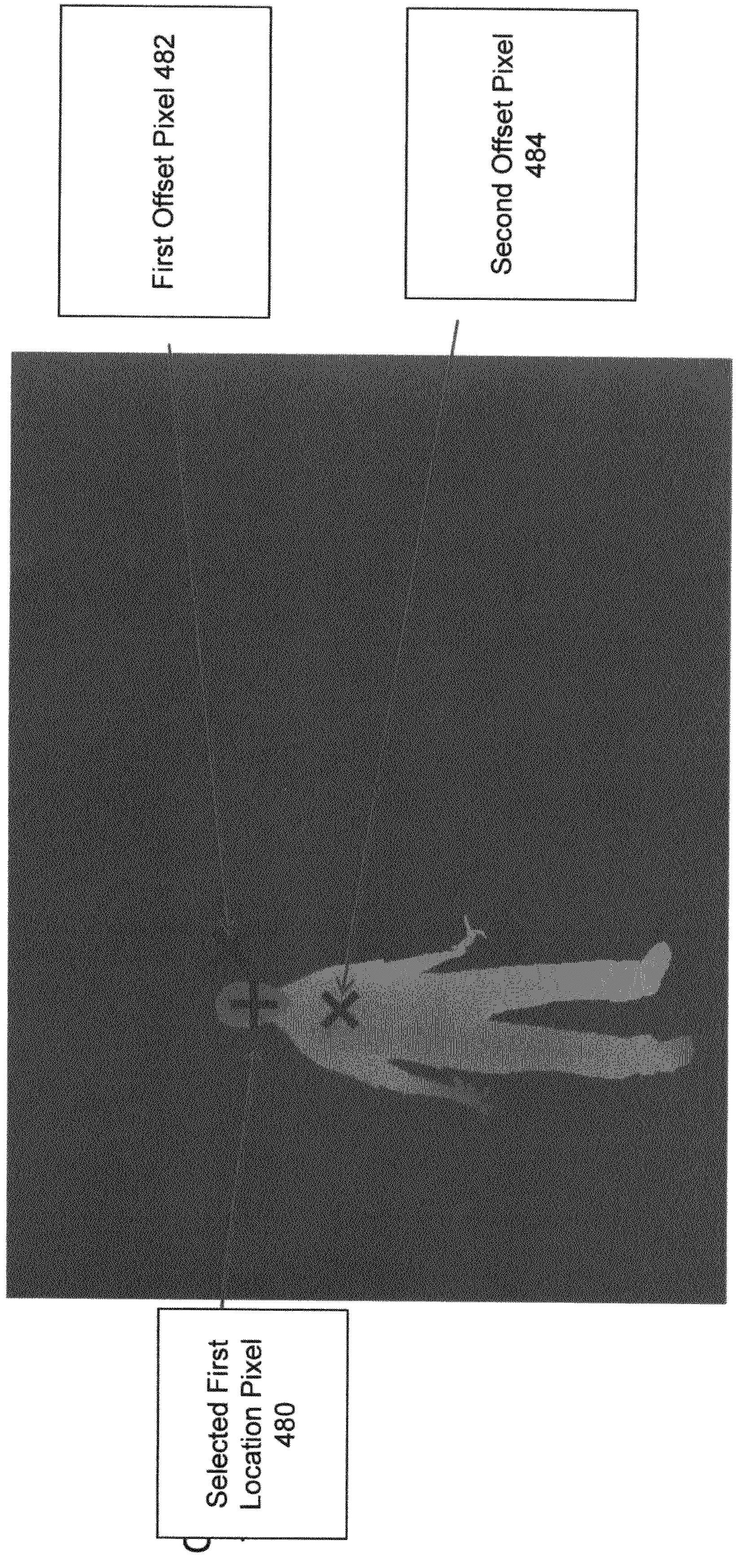
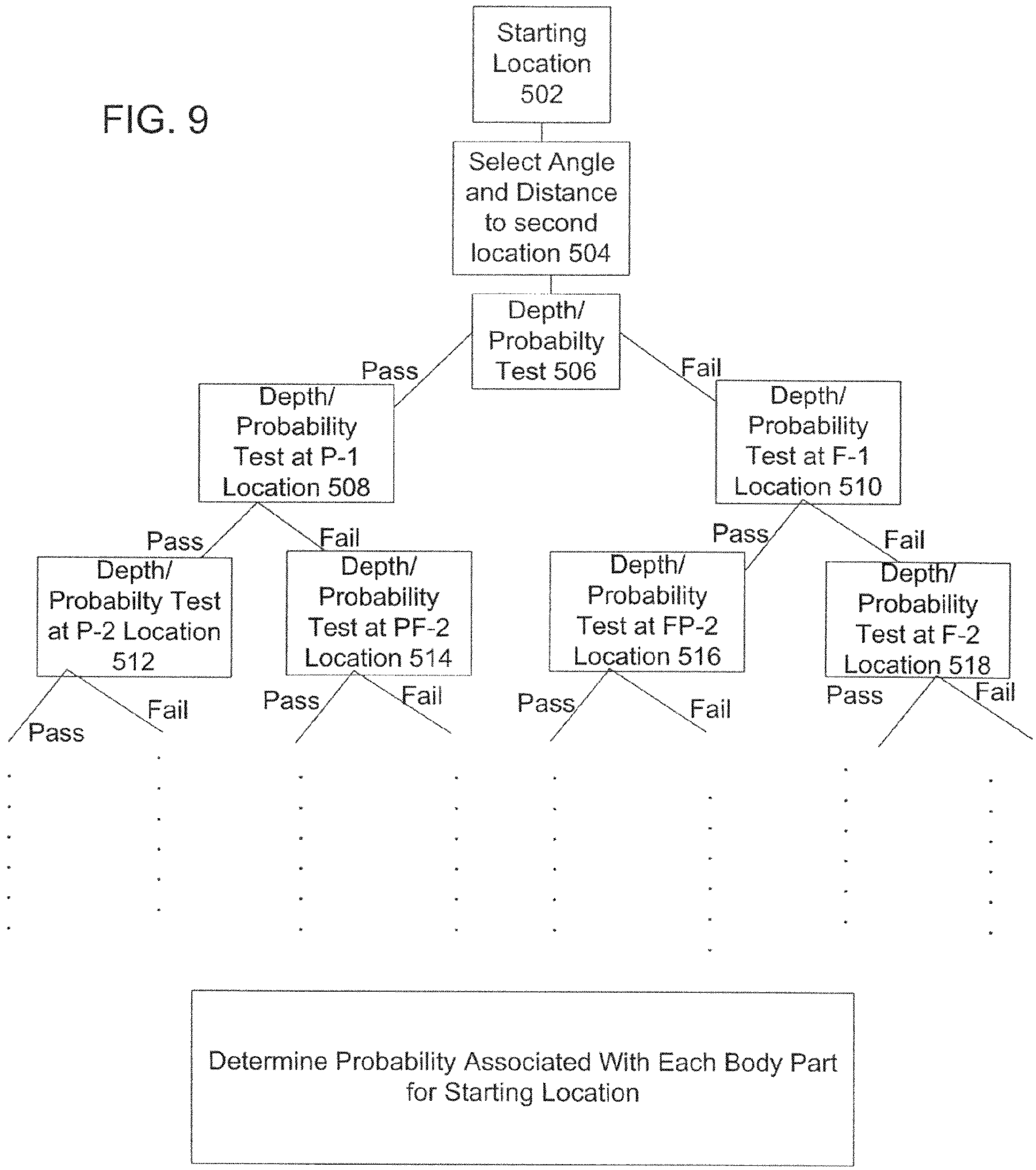
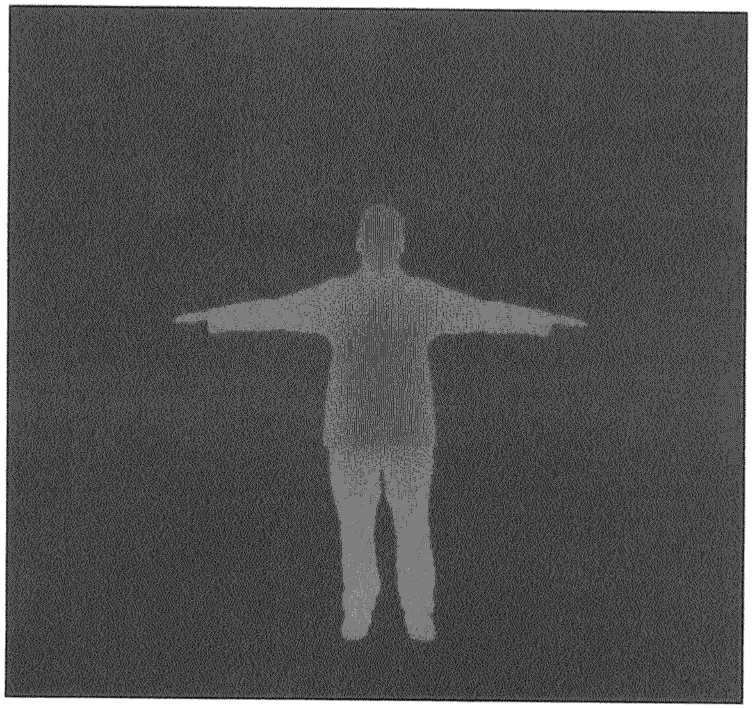

First Offset Pixel 482
Second Offset Pixel 484
Selected First Location Pixel 480

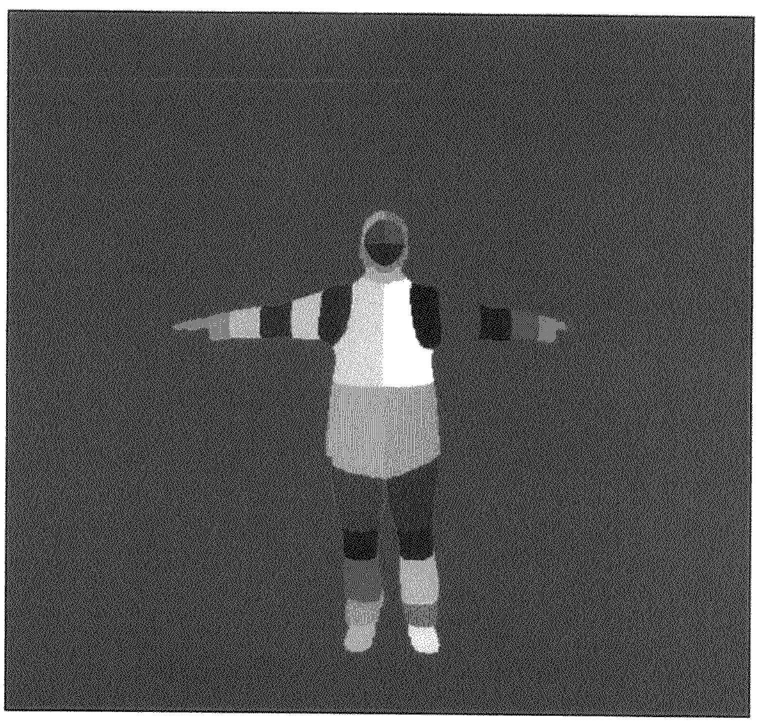
FIG. 8

FIG. 9


Starting Location 502
Select Angle and Distance to second location 504
Depth/ Probabilty Test 506
Pass
Fail
Depth/ Probability Test at P-1 Location 508
Depth/ Probability Test at F-1 Location 510
Pass
Fail
Pass
Fail
Depth/ Probabilty Test at P-2 Location 512
Depth/ Probability Test at PF-2 Location 514
Depth/ Probability Test at FP-2 Location 516
Depth/ Probability Test at F-2 Location 518
Pass
Fail
Pass
Fail
Pass
Fail
Pass
Fail
Determine Probability Associated With Each Body Part for Starting Location



550



552

FIG. 10

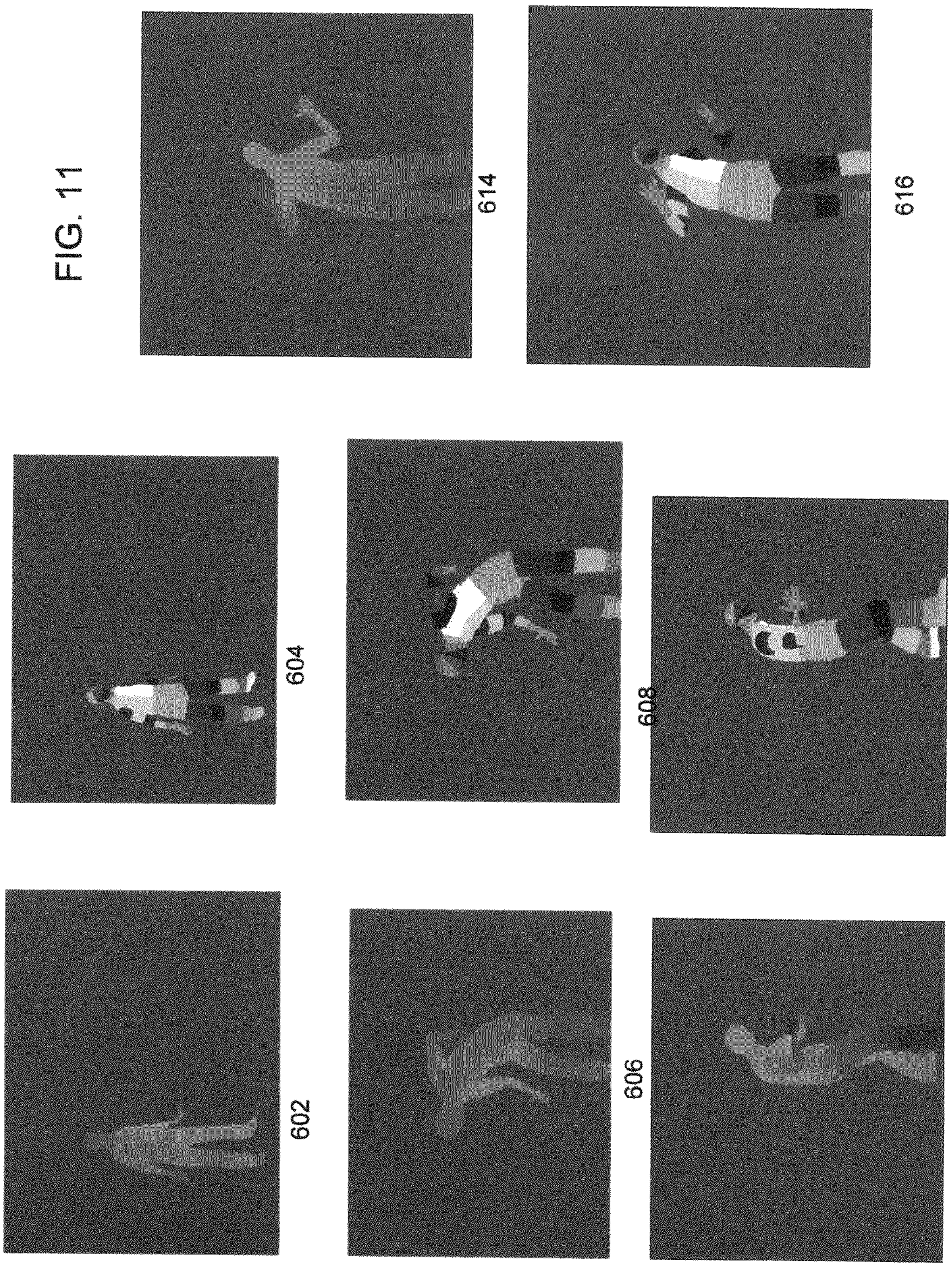


FIG. 11

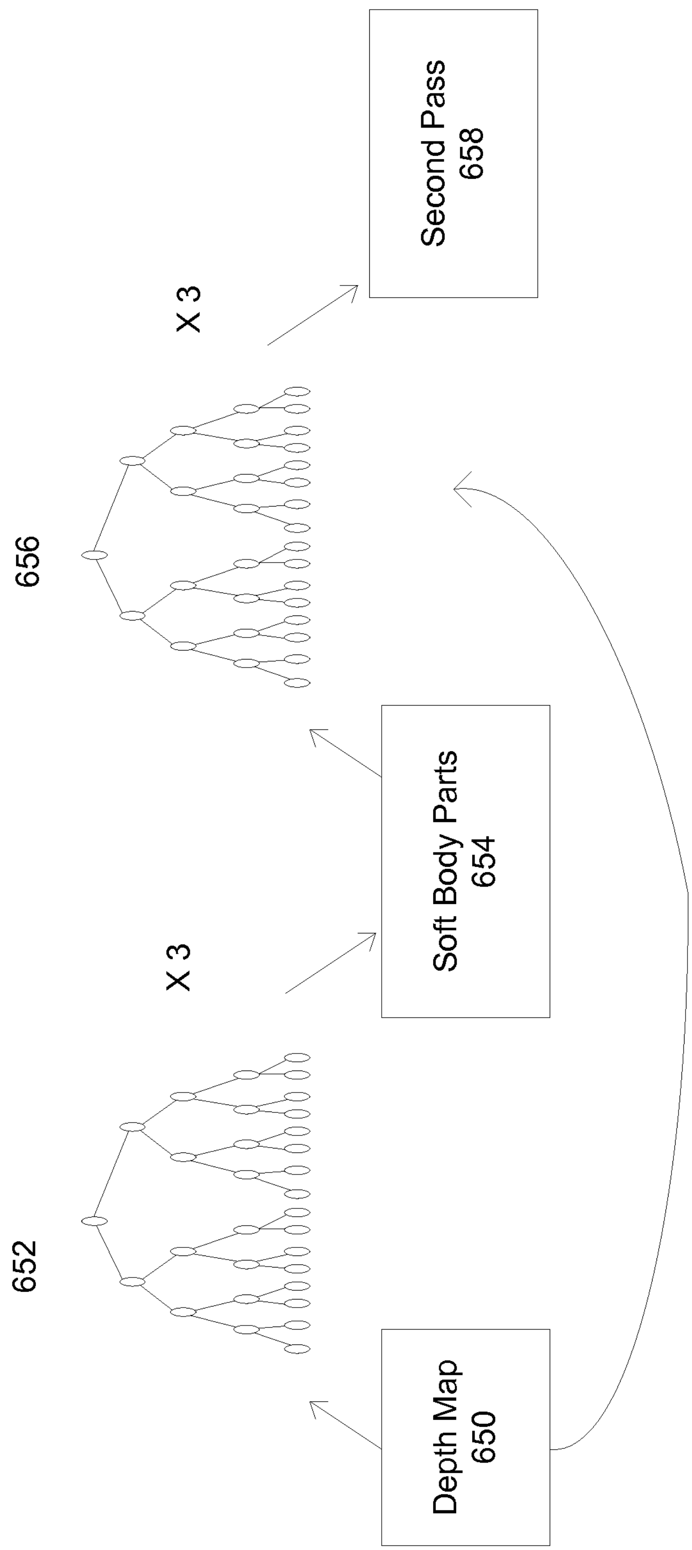
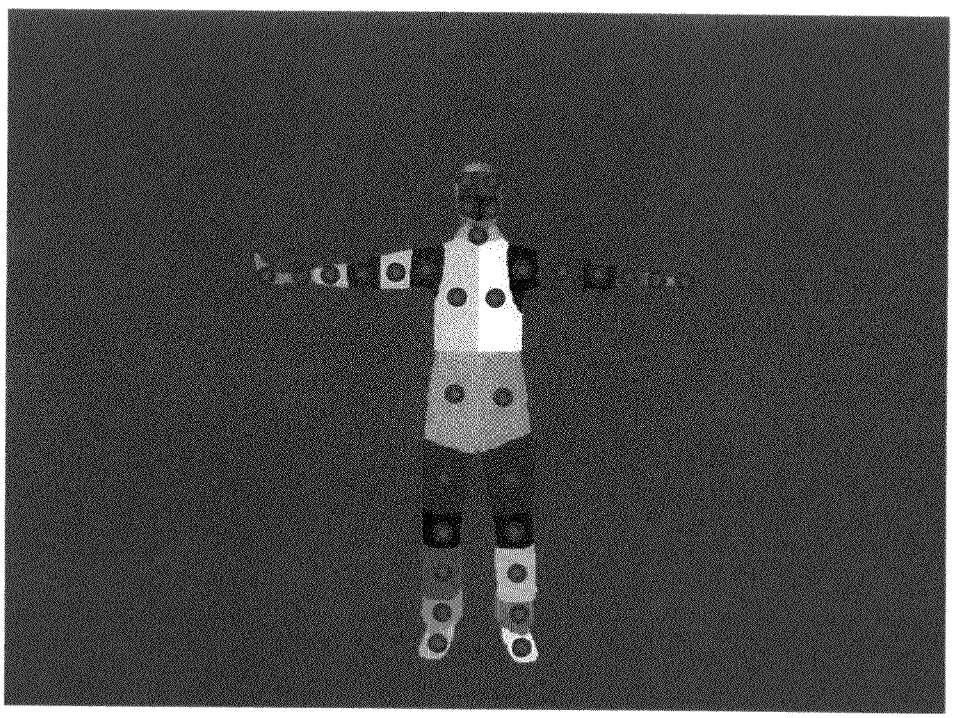

Depth Map
650
652
X 3
Soft Body Parts
654
656
X 3
Second Pass
658

FIG. 12

FIG. 13



HUMAN BODY POSE ESTIMATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/454,628 filed May 20, 2009 which claims the benefit of U.S. Provisional Application No. 61/174,878, titled "Human Body Pose Estimation" filed May 1, 2009. Each of which is hereby incorporated by references in its entirety.

BACKGROUND

In a typical computing environment, a user has an input device such as a keyboard, a mouse, a joystick or the like, which may be connected to the computing environment by a cable, wire, wireless connection or the like. If control of a computing environment were to be shifted from a connected controller to gesture or pose based control, the system will need effective techniques to be able to determine what poses or gestures a person is making Interpreting gestures or poses in a tracking and processing system without knowing the pose of a user's body may cause the system to misinterpret commands, or to miss them all together.

Further, a user of a tracking and processing system may stand at one of various different possible angles with respect to a capture device, and the user's gesture may appear differently to the capture device depending upon the particular angle of the user with respect to the capture device. For example, if the capture device is unaware that the user is not directly facing the capture device, then the user extending his arm directly forward could possibly be misinterpreted by the capture device as the user extending his arm partially to the left or the right. Thus, the system may not work properly without body pose estimation.

Accordingly, there is a need for technology that allows a tracking and processing system to determine the position of a user's body, and to therefore better interpret the gestures that the user is makes.

SUMMARY

Techniques for human body pose estimation are disclosed herein. Depth map images from a depth camera may be processed to calculate a probability that each pixel of the depth map is associated with one or more segments or body parts of a body. Body parts may then be constructed of the pixels and processed to define joints or nodes of those body parts. The nodes or joints may be provided to a system which may construct a model of the body from the various nodes or joints.

In an embodiment, a first pixel of a depth map may be associated with one or more body parts of one or more users. Association with a body part may mean that there is a high probability that the first pixel is located within the body part. This probability may be determined by measuring the background depth, the depth of the first pixel, and the depth of various other pixels around the first pixel.

The location and angle at which various other pixels around the first pixel may be measured for depth may be determined by a feature test training program. In one embodiment, each time the depth at a pixel is measured, a determination of whether the pixel is within the depth range of the body is made. Based on the determination, the distance and angle for the next test pixel may be provided. Selecting the test pixels in such a way may increase the efficiency and robustness of the system.

Body poses, which may include pointing, xyz coordinates, joints, rotation, area, and any other aspects of one or more body parts of user may be estimated for multiple users. In an embodiment, this may be accomplished by assuming a user segmentation. For example, values may be assigned to an image such that a value 0 represents background, value 1 represents user **1**, value 2 represents user **2**, etc. Given this player segmentation image, it is possible to classify all user **1** pixels and do a three dimensional centroid finding, and then repeat this process for subsequent users. In another embodiment, background subtraction may be performed and the remaining foreground pixels (belonging to the multiple users) may then be classified as associated with one or more body parts. In a further embodiment, the background may be considered another 'body part' and every pixel in the frame may be considered and associated with one or more body parts, including the background. When computing centroids, it may be ensured that each centroid is spatially localized, so that a respective body part is present for each user. The centroids may then be combined into coherent models by, for example, connecting neighboring body parts throughout each user's body.

In an embodiment, after one or more initial body part probabilities are calculated for each pixel, the initial probabilities for each pixel may be compared with the initial probabilities of one or more offset adjacent pixels to further refine the probability calculations. For example, if the initial probabilities suggest that adjacent pixels are in the same or adjacent body parts (i.e., head and neck), then this would increase the probabilities of the initial calculations. By contrast, if the initial probabilities suggest that adjacent pixels are in non-adjacent body parts (i.e., head and foot), then this would decrease the probabilities of the initial calculations.

BRIEF DESCRIPTION OF THE DRAWINGS

The file of this patent or application contains at least one drawing/photograph executed in color. Copies of this patent or patent application publication with color drawing(s)/photograph(s) will be provided by the Office upon request and payment of the necessary fee.

The systems, methods, and computer readable media for body pose estimation in accordance with this specification are further described with reference to the accompanying drawings in which:

FIGS. **1**A, **1**B, and **1**C illustrate an example embodiment of a target recognition, analysis, and tracking system with a user playing a game.

FIG. **2** illustrates an example embodiment of a capture device that may be used in a target recognition, analysis, and tracking system.

FIG. **3** depicts an example embodiment of a depth image.

FIG. **4** illustrates an example embodiment of a computing environment that may be used to interpret one or more poses or gestures in a body pose estimation system.

FIG. **5** illustrates another example embodiment of a computing environment that may be used to interpret one or more poses or gestures in a body pose estimation system.

FIG. **6** depicts a flow diagram of an example method for body pose estimation.

FIG. **7** depicts a flow diagram of an example depth feature test.

FIG. **8** depicts an example embodiment of pixels measured in a depth feature/probability test.

FIG. **9** depicts a flow diagram of an example embodiment of a depth feature/probability test tree.

FIG. **10** depicts an example embodiment of a segmented body used in body pose estimation.

FIG. **11** depicts example embodiments of poses of a user and corresponding segmented images which may be used in a training program to create feature tests.

FIG. **12** depicts an example embodiment of assigning probabilities associated with body parts using multiple feature tests.

FIG. **13** depicts an example embodiment of centroids/joints/nodes of body parts in body pose estimation.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

As will be described herein, a tracking and processing system determine body pose estimation. When a user makes a gesture or pose, a tracking and processing system may receive the gesture or pose and associate one or more commands with the user. In order to determine what response to provide the user of a computing environment, the system may need to be able to determine the body pose of the user. Body poses may also be used to determine skeletal models, determine the location of particular body parts and the like.

In an example embodiment, a tracking and processing system is provided with a capture device, wherein the capture device comprises a depth camera. The depth camera may capture a depth map of an image scene. The computing environment may perform one or more processes on the depth map to assign pixels on the depth map to segments of the users body. From these assigned body parts, the computing environment may obtain nodes, centroids or joint positions of the body parts, and may provide the nodes, joints or centroids to one or more processes to create a 3-D model of the body pose. In one aspect, the body pose is the three dimensional location of the set of body parts associated with a user. In another aspect, pose includes the three dimensional location of the body part, as well as the direction it is pointing, the rotation of the body segment or joint as well as any other aspects of the body part or segment.

FIGS. **1**A and **1**B illustrate an example embodiment of a configuration of a tracking and processing system **10** utilizing body pose estimation with a user **18** playing a boxing game. In an example embodiment, the tracking and processing system **10** may be used to, among other things, determine body pose, bind, recognize, analyze, track, associate to a human target, provide feedback, interpret poses or gestures, and/or adapt to aspects of the human target such as the user **18**.

As shown in FIG. **1**A, the tracking and processing system **10** may include a computing environment **12**. The computing environment **12** may be a computer, a gaming system or console, or the like. According to an example embodiment, the computing environment **12** may include hardware components and/or software components such that the computing environment **12** may be used to execute applications such as gaming applications, non-gaming applications, or the like.

As shown in FIG. **1**A, the tracking and processing system **10** may further include a capture device **20**. The capture device **20** may be, for example, a detector that may be used to monitor one or more users, such as the user **18**, such that poses performed by the one or more users may be captured, analyzed, processed, and tracked to perform one or more controls or actions within an application, as will be described in more detail below.

According to one embodiment, the tracking and processing system **10** may be connected to an audiovisual device **16** such as a television, a monitor, a high-definition television (HDTV), or the like that may provide game or application visuals and/or audio to the user **18**. For example, the computing environment **12** may include a video adapter such as a graphics card and/or an audio adapter such as a sound card that may provide audiovisual signals associated with the feedback about virtual ports and binding, game application, non-game application, or the like. The audiovisual device **16** may receive the audiovisual signals from the computing environment **12** and may then output the game or application visuals and/or audio associated with the audiovisual signals to the user **18**. According to one embodiment, the audiovisual device **16** may be connected to the computing environment **12** via, for example, an S-Video cable, a coaxial cable, an HDMI cable, a DVI cable, a VGA cable, a wireless connection or the like.

As shown in FIGS. **1**A and **1**B, the tracking and processing system **10** may be used to recognize, analyze, process, determine the pose of, and/or track a human target such as the user **18**. For example, the user **18** may be tracked using the capture device **20** such that the position, movements and size of user **18** may be interpreted as controls that may be used to affect the application being executed by computer environment **12**. Thus, according to one embodiment, the user **18** may move his or her body to control the application.

As shown in FIGS. **1**A and **1**B, in an example embodiment, the application executing on the computing environment **12** may be a boxing game that the user **18** may be playing. For example, the computing environment **12** may use the audiovisual device **16** to provide a visual representation of a boxing opponent **22** to the user **18**. The computing environment **12** may also use the audiovisual device **16** to provide a visual representation of a user avatar **24** that the user **18** may control with his or her movements on a screen **14**. For example, as shown in FIG. **1**B, the user **18** may throw a punch in physical space to cause the user avatar **24** to throw a punch in game space. Thus, according to an example embodiment, the computer environment **12** and the capture device **20** of the tracking and processing system **10** may be used to recognize and analyze the punch of the user **18** in physical space such that the punch may be interpreted as a game control of the user avatar **24** in game space.

The user **18** may be associated with a virtual port in computing environment **12**. Feedback of the state of the virtual port may be given to the user **18** in the form of a sound or display on audiovisual device **16**, a display such as an LED or light bulb, or a speaker on the computing environment **12**, or any other means of providing feedback to the user. The feedback may be used to inform a user when he is in a capture area of capture device **20**, if he is bound to the tracking and processing system **10**, what virtual port he is associated with, and when he has control over an avatar such as avatar **24**. Gestures and poses by user **18** may change the state of the system, and thus the feedback that the user receives from the system.

Other movements by the user **18** may also be interpreted as other controls or actions, such as controls to bob, weave, shuffle, block, jab, or throw a variety of different power punches. Furthermore, some movements may be interpreted as controls that may correspond to actions other than controlling the user avatar **24**. For example, the user may use movements to enter, exit, turn system on or off, pause, volunteer, switch virtual ports, save a game, select a level, profile or menu, view high scores, communicate with a friend, etc. Additionally, a full range of motion of the user **18** may be available, used, and analyzed in any suitable manner to interact with an application.

In FIG. **1**C, the human target such as the user **18** may have an object such as racket **21**. In such embodiments, the user of an electronic game may be holding the object such that the motions of the user and the object may be used to adjust and/or control parameters of the game, such as, for example, hitting an onscreen ball **23**. The motion of a user holding a racket **21** may be tracked and utilized for controlling an on-screen racket in an electronic sports game. In another example embodiment, the motion of a user holding an object may be tracked and utilized for controlling an on-screen weapon in an electronic combat game. Any other object may also be included, such as one or more gloves, balls, bats, clubs, guitars, microphones, sticks, pets, animals, drums and the like.

According to other example embodiments, the tracking and processing system **10** may further be used to interpret target movements as operating system and/or application controls that are outside the realm of games. For example, virtually any controllable aspect of an operating system and/or application may be controlled by movements of the target such as the user **18**.

As shown in FIG. **2**, according to an example embodiment, the image camera component **25** may include an IR light component **26**, a three-dimensional (3-D) camera **27**, and an RGB camera **28** that may be used to capture the depth image of a scene. For example, in time-of-flight analysis, the IR light component **26** of the capture device **20** may emit an infrared light onto the scene and may then use sensors (not shown) to detect the backscattered light from the surface of one or more targets and objects in the scene using, for example, the 3-D camera **27** and/or the RGB camera **28**. In some embodiments, pulsed infrared light may be used such that the time between an outgoing light pulse and a corresponding incoming light pulse may be measured and used to determine a physical distance from the capture device **20** to a particular location on the targets or objects in the scene. Additionally, in other example embodiments, the phase of the outgoing light wave may be compared to the phase of the incoming light wave to determine a phase shift. The phase shift may then be used to determine a physical distance from the capture device to a particular location on the targets or objects.

According to another example embodiment, time-of-flight analysis may be used to indirectly determine a physical distance from the capture device **20** to a particular location on the targets or objects by analyzing the intensity of the reflected beam of light over time via various techniques including, for example, shuttered light pulse imaging.

In another example embodiment, the capture device **20** may use a structured light to capture depth information. In such an analysis, patterned light (i.e., light displayed as a known pattern such as grid pattern or a stripe pattern) may be projected onto the scene via, for example, the IR light component **26**. Upon striking the surface of one or more targets or objects in the scene, the pattern may become deformed in response. Such a deformation of the pattern may be captured by, for example, the 3-D camera **27** and/or the RGB camera **28** and may then be analyzed to determine a physical distance from the capture device to a particular location on the targets or objects.

According to another embodiment, the capture device **20** may include two or more physically separated cameras that may view a scene from different angles, to obtain visual stereo data that may be resolved to generate depth information. Depth may also be determined by capturing images using one or more detectors that may be monochromatic, infrared, RGB or any other type of detector and performing a parallax calculation.

The capture device **20** may further include a microphone **30**. The microphone **30** may include a transducer or sensor that may receive and convert sound into an electrical signal. According to one embodiment, the microphone **30** may be used to reduce feedback between the capture device **20** and the computing environment **12** in the tracking and processing system **10**. Additionally, the microphone **30** may be used to receive audio signals that may also be provided by the user to control applications such as game applications, non-game applications, or the like that may be executed by the computing environment **12**.

The capture device **20** may further include a feedback component **31**. The feedback component **31** may comprise a light such as an LED or a light bulb, a speaker or the like. The feedback device may perform at least one of changing colors, turning on or off, increasing or decreasing in brightness, and flashing at varying speeds. The feedback component **31** may also comprise a speaker which may provide one or more sounds or noises as a feedback of one or more states. The feedback component may also work in combination with computing environment **12** or processor **32** to provide one or more forms of feedback to a user by means of any other element of the capture device, the tracking and processing system or the like.

In an example embodiment, the capture device **20** may further include a processor **32** that may be in operative communication with the image camera component **25**. The processor **32** may include a standardized processor, a specialized processor, a microprocessor, or the like that may execute instructions that may include instructions for receiving the depth image, determining whether a suitable target may be included in the depth image, converting the suitable target into a skeletal representation or model of the target, determining the body pose, or any other suitable instruction.

The capture device **20** may further include a memory component **34** that may store the instructions that may be executed by the processor **32**, images or frames of images captured by the 3-D camera or RGB camera, user profiles or any other suitable information, images, or the like. According to an example embodiment, the memory component **34** may include random access memory (RAM), read only memory (ROM), cache, Flash memory, a hard disk, or any other suitable storage component. As shown in FIG. **2**, in one embodiment, the memory component **34** may be a separate component in communication with the image capture component **25** and the processor **32**. According to another embodiment, the memory component **34** may be integrated into the processor **32** and/or the image capture component **25**.

As shown in FIG. **2**, the capture device **20** may be in communication with the computing environment **12** via a communication link **36**. The communication link **36** may be a wired connection including, for example, a USB connection, a Firewire connection, an Ethernet cable connection, or the like and/or a wireless connection such as a wireless 802.11b, g, a, or n connection. According to one embodiment, the computing environment **12** may provide a clock to the capture device **20** that may be used to determine when to capture, for example, a scene via the communication link **36**.

Additionally, the capture device **20** may provide the depth information and images captured by, for example, the 3-D camera **27** and/or the RGB camera **28**, and a skeletal model that may be generated by the capture device **20** or the computing environment to the computing environment **12** via the communication link **36**. The computing environment **12** may then use the skeletal model, depth information, and captured images to, for example, create a virtual screen, adapt the user interface and control an application such as a game or word processor. For example, as shown, in FIG. **2**, the computing environment **12** may include a gestures library **190**. The gestures library **190** may include a collection of gesture filters, each comprising information concerning a gesture that may be performed by the skeletal model (as the user moves). The data captured by the cameras **26**, **27** and device **20** in the form of the skeletal model and movements associated with it may be compared to the gesture filters in the gesture library **190** to identify when a user (as represented by the skeletal model) has performed one or more gestures. Those gestures or poses may be associated with various controls of an application. Thus, the computing environment **12** may use the gestures library **190** to interpret movements of the skeletal model and to control an application based on the movements.

FIG. **3** illustrates an example embodiment of a depth image **60** that may be received by the tracking and processing system and/or the computing environment. According to an example embodiment, the depth image **60** may be an image or frame of a scene captured by, for example, the 3-D camera **27** and/or the RGB camera **28** of the capture device **20** described above with respect to FIG. **2**. As shown in FIG. **3**, the depth image **60** may include a human target **62** and one or more non-human targets **64** such as a wall, a table, a monitor, or the like in the captured scene. As described above, the depth image **60** may include a plurality of observed pixels where each observed pixel has an observed depth value associated therewith. For example, the depth image **60** may include a two-dimensional (2-D) pixel area of the captured scene where each pixel in the 2-D pixel area may represent a depth value such as a length or distance in, for example, centimeters, millimeters, or the like of a target or object in the captured scene from the capture device.

According to one embodiment, a depth image such as depth image **60** or an image on an RGB camera such as camera **28**, or an image on any other detector may be processed and used to determine the shape and size of a target. In another embodiment, the depth image **60** may be used to determine the body pose of a user. The body may be divided into a series of segments and each pixel of a depth map **60** may be assigned a probability that it is associated with each segment. This information may be provided to one or more processes which may determine the location of nodes, joints, centroids or the like to determine a skeletal model and interpret the motions of a user **62** for pose or gesture based command.

Referring back to FIG. **2**, in one embodiment, upon receiving the depth image, the depth image may be downsampled to a lower processing resolution such that the depth image may be more easily used and/or more quickly processed with less computing overhead. Additionally, one or more high-variance and/or noisy depth values may be removed and/or smoothed from the depth image; portions of missing and/or removed depth information may be filled in and/or reconstructed; and/or any other suitable processing may be performed on the received depth information may such that the depth information may used to size a virtual screen on a user as described above.

FIG. **4** illustrates an example embodiment of a computing environment that may be used to interpret one or more gestures in a target recognition, analysis, and tracking system. The computing environment such as the computing environment **12** described above with respect to FIGS. **1A-2** may be a multimedia console **100**, such as a gaming console. As shown in FIG. **4**, the multimedia console **100** has a central processing unit (CPU) **101** having a level 1 cache **102**, a level 2 cache **104**, and a flash ROM (Read Only Memory) **106**. The level 1 cache **102** and a level 2 cache **104** temporarily store data and hence reduce the number of memory access cycles, thereby improving processing speed and throughput. The CPU **101** may be provided having more than one core, and thus, additional level 1 and level 2 caches **102** and **104**. The flash ROM **106** may store executable code that is loaded during an initial phase of a boot process when the multimedia console **100** is powered ON.

A graphics processing unit (GPU) **108** and a video encoder/video codec (coder/decoder) **114** form a video processing pipeline for high speed and high resolution graphics processing. Data is carried from the graphics processing unit **108** to the video encoder/video codec **114** via a bus as well as to the CPU. The video processing pipeline outputs data to an AN (audio/video) port **140** for transmission to a television or other display. A memory controller **110** is connected to the GPU **108** to facilitate processor access to various types of memory **112**, such as, but not limited to, a RAM (Random Access Memory).

The multimedia console **100** includes an I/O controller **120**, a system management controller **122**, an audio processing unit **123**, a network interface controller **124**, a first USB host controller **126**, a second USB controller **128** and a front panel I/O subassembly **130** that are preferably implemented on a module **118**. The USB controllers **126** and **128** serve as hosts for peripheral controllers **142(1)-142(2)**, a wireless adapter **148**, and an external memory device **146** (e.g., flash memory, external CD/DVD ROM drive, removable media, etc.). The network interface **124** and/or wireless adapter **148** provide access to a network (e.g., the Internet, home network, etc.) and may be any of a wide variety of various wired or wireless adapter components including an Ethernet card, a modem, a Bluetooth module, a cable modem, and the like.

System memory **143** is provided to store application data that is loaded during the boot process. A media drive **144** is provided and may comprise a DVD/CD drive, hard drive, or other removable media drive, etc. The media drive **144** may be internal or external to the multimedia console **100**. Application data may be accessed via the media drive **144** for execution, playback, etc. by the multimedia console **100**. The media drive **144** is connected to the I/O controller **120** via a bus, such as a Serial ATA bus or other high speed connection (e.g., IEEE 1394).

The system management controller **122** provides a variety of service functions related to assuring availability of the multimedia console **100**. The audio processing unit **123** and an audio codec **132** form a corresponding audio processing pipeline with high fidelity and stereo processing. Audio data is carried between the audio processing unit **123** and the audio codec **132** via a communication link. The audio processing pipeline outputs data to the A/V port **140** for reproduction by an external audio player or device having audio capabilities.

The front panel I/O subassembly **130** supports the functionality of the power button **150** and the eject button **152**, as well as any LEDs (light emitting diodes) or other indicators exposed on the outer surface of the multimedia console **100**. A system power supply module **136** provides power to the components of the multimedia console **100**. A fan **138** cools the circuitry within the multimedia console **100**.

The front panel I/O subassembly **130** may include LEDs, a visual display screen, light bulbs, a speaker or any other means that may provide audio or visual feedback of the state of control of the multimedia control **100** to a user **18**. For example, if the system is in a state where no users are detected by capture device **20**, such a state may be reflected on front panel I/O subassembly **130**. If the state of the system changes, for example, a user becomes bound to the system, the feedback state may be updated on the front panel I/O subassembly to reflect the change in states.

The CPU **101**, GPU **108**, memory controller **110**, and various other components within the multimedia console **100** are interconnected via one or more buses, including serial and parallel buses, a memory bus, a peripheral bus, and a processor or local bus using any of a variety of bus architectures. By way of example, such architectures can include a Peripheral Component Interconnects (PCI) bus, PCI-Express bus, etc.

When the multimedia console **100** is powered ON, application data may be loaded from the system memory **143** into memory **112** and/or caches **102**, **104** and executed on the CPU **101**. The application may present a graphical user interface that provides a consistent user experience when navigating to different media types available on the multimedia console **100**. In operation, applications and/or other media contained within the media drive **144** may be launched or played from the media drive **144** to provide additional functionalities to the multimedia console **100**.

The multimedia console **100** may be operated as a standalone system by simply connecting the system to a television or other display. In this standalone mode, the multimedia console **100** allows one or more users to interact with the system, watch movies, or listen to music. However, with the integration of broadband connectivity made available through the network interface **124** or the wireless adapter **148**, the multimedia console **100** may further be operated as a participant in a larger network community.

When the multimedia console **100** is powered ON, a set amount of hardware resources are reserved for system use by the multimedia console operating system. These resources may include a reservation of memory (e.g., 16 MB), CPU and GPU cycles (e.g., 5%), networking bandwidth (e.g., 8 kbs), etc. Because these resources are reserved at system boot time, the reserved resources do not exist from the application's view.

In particular, the memory reservation preferably is large enough to contain the launch kernel, concurrent system applications and drivers. The CPU reservation is preferably constant such that if the reserved CPU usage is not used by the system applications, an idle thread will consume any unused cycles.

With regard to the GPU reservation, lightweight messages generated by the system applications (e.g., popups) are displayed by using a GPU interrupt to schedule code to render popup into an overlay. The amount of memory required for an overlay depends on the overlay area size and the overlay preferably scales with screen resolution. Where a full user interface is used by the concurrent system application, it is preferable to use a resolution independent of application resolution. A scaler may be used to set this resolution such that the need to change frequency and cause a TV resynch is eliminated.

After the multimedia console **100** boots and system resources are reserved, concurrent system applications execute to provide system functionalities. The system functionalities are encapsulated in a set of system applications that execute within the reserved system resources described above. The operating system kernel identifies threads that are system application threads versus gaming application threads. The system applications are preferably scheduled to run on the CPU **101** at predetermined times and intervals in order to provide a consistent system resource view to the application. The scheduling is to minimize cache disruption for the gaming application running on the console.

When a concurrent system application requires audio, audio processing is scheduled asynchronously to the gaming application due to time sensitivity. A multimedia console application manager (described below) controls the gaming application audio level (e.g., mute, attenuate) when system applications are active.

Input devices (e.g., controllers **142(1)** and **142(2)**) are shared by gaming applications and system applications. The input devices are not reserved resources, but are to be switched between system applications and the gaming application such that each will have a focus of the device. The application manager preferably controls the switching of input stream, without knowledge the gaming application's knowledge and a driver maintains state information regarding focus switches. The cameras **27**, **28** and capture device **20** may define additional input devices for the console **100**.

FIG. **5** illustrates another example embodiment of a computing environment that may be the computing environment **12** shown in FIGS. **1A-2** used to interpret one or more poses or gestures in a tracking and processing system. The computing system environment of FIG. **5** is only one example of a suitable computing environment and is not intended to suggest any limitation as to the scope of use or functionality of the presently disclosed subject matter. Neither should the computing environment **12** be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary operating environment of FIG. **5**. In some embodiments the various depicted computing elements may include circuitry configured to instantiate specific aspects of the present disclosure. For example, the term circuitry used in the disclosure can include specialized hardware components configured to perform function(s) by firmware or switches. In other examples embodiments the term circuitry can include a general purpose processing unit, memory, etc., configured by software instructions that embody logic operable to perform function (s). In example embodiments where circuitry includes a combination of hardware and software, an implementer may write source code embodying logic and the source code can be compiled into machine readable code that can be processed by the general purpose processing unit. Since one skilled in the art can appreciate that the state of the art has evolved to a point where there is little difference between hardware, software, or a combination of hardware/software, the selection of hardware versus software to effectuate specific functions is a design choice left to an implementer. More specifically, one of skill in the art can appreciate that a software process can be transformed into an equivalent hardware structure, and a hardware structure can itself be transformed into an equivalent software process. Thus, the selection of a hardware implementation versus a software implementation is one of design choice and left to the implementer.

In FIG. **5**, the computing environment comprises a computer **241**, which typically includes a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer **241** and includes both volatile and nonvolatile media, removable and non-removable media. The system memory **222** includes computer storage media in the form of volatile and/or nonvolatile memory such as read only memory (ROM) **223** and random access memory (RAM) **260**. A basic input/output system **224** (BIOS), containing the basic routines that help to transfer information between elements within computer **241**, such as during start-up, is typically stored in ROM **223**. RAM **260** typically contains data and/or program modules that are immediately accessible to and/or presently being operated on by processing unit **259**. By way of example, and not limitation, FIG. **5** illustrates operating system **225**, application programs **226**, other program modules **227**, and program data **228**.

The computer **241** may also include other removable/non-removable, volatile/nonvolatile computer storage media. By way of example only, FIG. **5** illustrates a hard disk drive **238** that reads from or writes to non-removable, nonvolatile magnetic media, a magnetic disk drive **239** that reads from or writes to a removable, nonvolatile magnetic disk **254**, and an optical disk drive **240** that reads from or writes to a removable, nonvolatile optical disk **253** such as a CD ROM or other optical media. Other removable/non-removable, volatile/nonvolatile computer storage media that can be used in the exemplary operating environment include, but are not limited to, magnetic tape cassettes, flash memory cards, digital versatile disks, digital video tape, solid state RAM, solid state ROM, and the like. The hard disk drive **238** is typically connected to the system bus **221** through a non-removable memory interface such as interface **234**, and magnetic disk drive **239** and optical disk drive **240** are typically connected to the system bus **221** by a removable memory interface, such as interface **235**.

The drives and their associated computer storage media discussed above and illustrated in FIG. **5**, provide storage of computer readable instructions, data structures, program modules and other data for the computer **241**. In FIG. **5**, for example, hard disk drive **238** is illustrated as storing operating system **258**, application programs **257**, other program modules **256**, and program data **255**. Note that these components can either be the same as or different from operating system **225**, application programs **226**, other program modules **227**, and program data **228**. Operating system **258**, application programs **257**, other program modules **256**, and program data **255** are given different numbers here to illustrate that, at a minimum, they are different copies. A user may enter commands and information into the computer **241** through input devices such as a keyboard **251** and pointing device **252**, commonly referred to as a mouse, trackball or touch pad. Other input devices (not shown) may include a microphone, joystick, game pad, satellite dish, scanner, or the like. These and other input devices are often connected to the processing unit **259** through a user input interface **236** that is coupled to the system bus, but may be connected by other interface and bus structures, such as a parallel port, game port or a universal serial bus (USB). The cameras **27**, **28** and capture device **20** may define additional input devices for the console **100**. A monitor **242** or other type of display device is also connected to the system bus **221** via an interface, such as a video interface **232**. In addition to the monitor, computers may also include other peripheral output devices such as speakers **244** and printer **243**, which may be connected through a output peripheral interface **233**.

The computer **241** may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer **246**. The remote computer **246** may be a personal computer, a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to the computer **241**, although only a memory storage device **247** has been illustrated in FIG. **5**. The logical connections depicted in FIG. **5** include a local area network (LAN) **245** and a wide area network (WAN) **249**, but may also include other networks. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets and the Internet.

When used in a LAN networking environment, the computer **241** is connected to the LAN **245** through a network interface or adapter **237**. When used in a WAN networking environment, the computer **241** typically includes a modem **250** or other means for establishing communications over the WAN **249**, such as the Internet. The modem **250**, which may be internal or external, may be connected to the system bus **221** via the user input interface **236**, or other appropriate mechanism. In a networked environment, program modules depicted relative to the computer **241**, or portions thereof, may be stored in the remote memory storage device. By way of example, and not limitation, FIG. **5** illustrates remote application programs **248** as residing on memory device **247**. It will be appreciated that the network connections shown are exemplary and other means of establishing a communications link between the computers may be used.

FIG. **6** depicts a block diagram **300** whereby body pose estimation may be performed. In one embodiment, at **302**, a depth map such as depth map **60** may be received by the tracking and processing system. Probabilities associated with one or more virtual body parts may be assigned to pixels on a depth map at **304**. A centroid may be calculated for sets of associated pixels associated with a virtual body part, which may be a node, joint or centroid at **306**. Centroids may be representations of joints or nodes of a body, and may be calculated using any mathematical algorithm, including, for example, averaging the coordinates of every pixel in a depth map having a threshold probability that it is associated with a body part, or, as another example, a linear regression technique. At **308**, the various nodes, joints or centroids associated with the body parts may be combined into a model, which may be provided to one or more programs in a tracking and processing system. The model may include not only the location in three dimensions of the joints or body parts, but may also include the rotation of a joint or any other information about the pointing of the body part.

Body poses may be estimated for multiple users. In an embodiment, this may be accomplished by assuming a user segmentation. For example, values may be assigned to an image such that a value 0 represents background, value 1 represents user **1**, value 2 represents user **2**, etc. Given this player segmentation image, it is possible to classify all user **1** pixels and do a centroid finding, and then repeat this process for subsequent users. In another embodiment, background subtraction may be performed and the remaining foreground pixels (belonging to the multiple users) may then be classified. When computing centroids, it may be ensured that each centroid is spatially localized, so that a respective body part is present for each user. The centroids may then be combined into coherent models by, for example, connecting neighboring body parts throughout each user's body.

FIG. **7** depicts a sample flow chart for assigning probabilities associated with virtual body parts to a depth map. In an example embodiment, the process of FIG. **7** may be performed at **304** of FIG. **6**. Process **350** may employ a depth map received at **302** to assign probabilities associated with virtual body parts at **304**. One or more background depths on a depth map may be established at **352**. For example, one background depth may correspond to a wall in the back of a room, other background depths may correspond to other humans or objects in the room. These background depths may be used later in flowchart of FIG. **7** to determine if a pixel on the depth map is part of a particular user's body or whether the pixel may be associated with the background.

At **353**, a first location may be selected in the depth map. The depth of the first location may be determined at **354**. At **356**, the depth of the first location may be compared with one or more background depths. If the first location depth is at the same or within a specified threshold range of a background depth, then, at **358**, the first location is determined to be part of the background and not part of any body parts. If the first location is not at or within a specified threshold range of a background depth, an offset location, referenced with respect to the first location, may be selected at **360**. At **362**, the depth of the offset location may be determined and a depth test may be performed to determine if the offset location is background. At **354**, it is determined whether any additional offset locations are desired.

The determination of whether or not to select additional offset locations, as well as the angle and distance of the additional offset locations from the first location, may be made based in part on the depth of the previous offset location (s) with respect to the first location and/or the background. These determinations may also be made based on additional factors such as the training module described below. In one embodiment, the offsets will scale with depth. For example, if a user is very close to a detector in a capture area, depth may be measured at large offset distances from the first pixel. If the user were to move twice as far from a detector, then the offset distances may decrease by a factor of two. In one embodiment, this scaling causes the depth offset tests to be invariant. Any number of offset locations may be selected and depth tested, after which a probability that the first location is associated with one or more body parts is calculated at **366**. This calculation may be based in part on the depth of the first location and the offset locations with respect to the one or more background depths. This calculation may also be made based on additional factors such as the training module described below.

In another embodiment, **352** may not be performed. In this embodiment, each pixel in a depth map is examined for depth at **354**, and then the method proceeds directly to choosing offset locations at **360**. In such an example, every pixel in a depth map may be examined for depth or for the probability that it is associated with one or more body parts and/or background. From the determinations made at the first pixel and the offset locations, probabilities may be associated with one or more pixels.

FIG. **8** depicts an instance of the flow chart referenced in FIG. **7**. In the flow chart of FIG. **7**, a series of feature tests may be used to determine the probability that a pixel in a depth map is associated with one or more body parts. A first location pixel is selected at **480**. A first offset pixel is examined at **482**, and a second offset pixel is examined at **484**. As more pixels are examined for depth, the probability that a particular pixel is associated with a part of the body may decrease or increase. This probability may be provided to other processes in a tracking and processing system.

In another example depicted by FIG. **8**, a first location pixel of a depth map is selected at **480**, wherein the depth map has probabilities that each pixel in the depth map is associated with one or more body parts already assigned to each pixel. A second offset pixel is examined for its associated probability at **484**. As more pixels are examined for their associated probabilities, a second pass at the probability associated with the first pixel may provide a more accurate determination of the body part associated with the pixel. This probability may be provided to other processes in a tracking and processing system.

FIG. **9** depicts a flow chart of another example implementation of feature testing in body pose estimation. A depth map is received and a first pixel location is selected at **502**. This may be the pixel depicted at FIG. **8** as the first location. If the first pixel is at the background depth, then probabilities associated with each body part may be zero. If, however, the first pixel is not at the background depth, an angle and distance to a second pixel may be selected at **504**.

In another embodiment, a background depth is not determined, instead depth tests and the surrounding offset depth tree tests may be performed at each pixel, regardless of its depth.

In another embodiment, the depth map received at **502** already has the probability that each pixel is associated with one or more body parts assigned to each pixel. Accordingly, instead of testing depth at the first pixel and at offset locations, the probabilities may be tested.

A depth/probability test may be performed on the second pixel at **506**. If the second pixel fails the depth/probability test (i.e. it is at the background depth/probability, the depth/probability of a second user, not within the range of a users body or the like) then location F-**1** is selected at **510**. If, however, the second pixel passes the depth/probability test (i.e. it is within a threshold of the body depth/probability), then location P-**1** is selected at **508**. Depth/probability tests will then be performed on third pixels at **508** or **510**, and based on whether the third pixels pass or fail the depth/probability test, other pixel locations will be selected at one of **512**, **514**, **516** or **518**. While these locations may, in some cases, be the same, they may also vary widely in location based on the results of the depth/probability tests.

In an example embodiment, depth/probability tests on any number of pixels may be performed with reference to a single pixel. For example, 16 tests may be performed, where each depth/probability test is at a different pixel. By performing some quantity of depth/probability tests, the probability that a pixel is associated with each body part may be assigned to each pixel. As another example, only one test may need to be performed on a particular pixel in order to determine the probability that it is associated with one or more body parts.

FIG. **10** depicts an example image that may come from a capture device, such as capture device **20**, a graphics package, or other 3-D rendering along with a segmented body image of the example image. Original image **550** may be may be a depth map or other image from the capture device. In an example embodiment, the image of a body may be segmented into many parts as in segmented image **552**, and each pixel in a depth map may be associated with a probability for each of the segments in FIG. **10**. This probability may be determined using the methods, processes and systems described with respect to FIGS. **7**, **8** and **9**.

FIG. **11** depicts a series of images of poses from one or more users. For each pose, an image that may be received from a capture device such as capture device **20** is shown adjacent to an image of the pose that has been segmented into parts.

In a first embodiment, the tracking and processing system may receive the non-segmented images **602**, **606**, **610**, and **614**, and use the processes described at FIGS. **7**, **8** and **9** to determine the probability that each pixel in the image is associated with each of the segmented body parts. The purpose of the processes described in FIGS. **7**, **8** and **9** may be to segment the body into each of the parts shown at **604**, **608**, **612** and **616**. These segmented parts may be used by one or more computer processes to determine the body pose of the user.

In a second embodiment, these images may be used in a feature test training module to determine the feature test of FIGS. **7**, **8**, and **9**. Recall from FIGS. **7**, **8**, and **9** that a depth test may be performed on a pixel, and it either passes or fails, and based on the pass or fail, a next location will be selected. In one embodiment, the next location selected is not arbitrary, but is selected based on a training module. A training module may involve inputting a volume of thousands, hundreds of thousands, millions or any number of segmented poses such as those shown in FIG. **11** into a program. The program may perform one or more operations on the volume of poses to determine optimal feature tests for each pass or fail for the full volume, or some selection of poses. This optimized series of feature tests may be known as feature test trees.

A volume of poses input into a feature test training module may not contain every possible pose by a user. Further, it may increase the efficiency of the program to create several feature test training modules, each of which are based on a separate volume of body poses. Accordingly, the feature tests at each step of a feature test tree may be different and the final probabilities associated with each segment of a body at the conclusion of a test tree may also be different. In one embodiment, several feature test trees are provided for each pixel and the probabilities output from each test tree may be averaged or otherwise combined to provide a segmented image of a body pose.

FIG. **12** depicts an example flow chart to determine body segment probabilities associated with each pixel in human body pose estimation. At **650** a depth map such as the depth map shown in FIG. **3** may be received from a capture device **20**. This depth map may be provided to a series of feature test trees at **652**. In FIG. **12**, three feature test trees, each having been trained on a different volume of body poses, test each pixel of a depth map. The probability that each pixel is associated with each segment of the body is determined at **654** as the soft body parts. In an example embodiment, the process stops here and these probabilities may be used to obtain the joints/nodes/centroids of FIG. **6** at **306**.

In another embodiment, at **656**, the depth map may again be provided to a series of feature test trees, each of which may have been created using a different volume of body pose images. In FIG. **12**, this second series of feature tests contains three trees, each of which may output a probability for each pixel of the depth map associated with each segment of a body. At **658**, the probabilities from the second set of feature test trees **656** and the soft body parts from 654 may be combined by averaging or some other method to determine the second pass of the body parts. FIG. **12** shows two sets of three feature test trees, however, the number of feature test trees is not limited by the number three, nor are the number of passes limited by FIG. **12**. There may be any number of feature test trees and any number of passes.

In another embodiment, at **656**, the depth map provided to the series of feature test trees may have the probability that each pixel of a depth map is associated with one or more body parts already associated with each pixel. For example, the probability maps determined by the feature test trees at **652** may be provided to the feature test trees at **656**. In such a circumstance, instead of depth test training programs and trees, the system instead utilizes probability test training programs and trees. The number of trees and passes is not limited in any way, and the trees may be any combination of depth and probability feature tests.

FIG. **13** depicts a segmented body pose image wherein each segment contains a node/joint/centroid, such as those described at **306** with reference to FIG. **6**. These joints/nodes/centroids may be determined by taking the centroid of all of the pixels associated with a body part segment after performing the feature tests of FIGS. **7**, **8**, **9**, and **12**. Other methods may also be used to determine the location of the nodes/centroids/joints. For example, a filtering process may remove outlying pixels or the like, after which a process may take place to determine the location of the joints/nodes/centroids.

The joints/nodes/centroids of FIG. **13** may be used to construction a skeletal model, or otherwise represent the body pose of a user. This model may be used by the tracking and processing system in any way, including determining the commands of one or more users, identifying one or more users and the like.

It should be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific embodiments or examples are not to be considered limiting. The specific routines or methods described herein may represent one or more of any number of processing strategies. As such, various acts illustrated may be performed in the sequence illustrated, in other sequences, in parallel, or the like. Likewise, the order of the above-described processes may be changed.

Additionally, the subject matter of the present disclosure includes combinations and subcombinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as equivalents thereof.

What is claimed:

1. A method for determining a position of at least part of a body, the method comprising:

receiving, at a computing system, a depth image that includes the at least part of the body;

determining, at the computing system, that a first pixel in the depth image corresponds to the at least part of the body; and

determining, at the computing system, that a second pixel in the depth image corresponds to the at least part of the body based on an angle and a distance of the second pixel relative to the first pixel.

2. The method of claim **1**,

wherein determining that the first pixel in the depth image corresponds to the at least part of the body comprises determining a first probability that the first pixel in the depth image corresponds to the at least part of the body, and

wherein determining that the second pixel in the depth image corresponds to the at least part of the body comprises: determining that the second pixel in the depth image corresponds to the at least part of the body based on the angle and the distance of the second pixel relative to the first pixel, and the first probability.

3. The method of claim **2**, further comprising:

determining that a third pixel in the depth image has a zero probability of corresponding to the at least part of the body based on the third pixel having a depth value associated with a background.

4. The method of claim **1**, further comprising:

selecting a third pixel among a plurality of pixels in the depth image for determination of whether the third pixel corresponds to the at least part of the body based on determining that the second pixel in the depth image corresponds to the at least part of the body, and based on an angle and a distance of the third pixel relative to the second pixel.

5. The method of claim **1**, further comprising:

determining the angle and the distance of the second pixel relative to the first pixel based on a decision tree.

6. The method of claim **1**, further comprising:

determining the angle and the distance of the second pixel relative to the first pixel invariantly with respect to depth.

7. The method of claim **1**, wherein determining that the second pixel in the depth image corresponds to the at least part of the body comprises:

determining that the second pixel in the depth image corresponds to the at least part of the body based on the angle and the distance of the second pixel relative to the first pixel, and a depth value of the first pixel.

8. A system for determining a position of at least part of a body, comprising:

computing memory bearing instructions that, upon execution by one or more processors, cause the system at least to:

receive a depth image that includes at least part of the body;

determine that a first pixel in the depth image corresponds to the at least part of the body; and

determine that a second pixel in the depth image corresponds to the at least part of the body based on an angle and a distance of the second pixel relative to the first pixel.

9. The system of claim **8**,

wherein the memory further bears instructions that, upon execution by the processor, cause the system at least to:

select the second pixel among a plurality of pixels in the depth image for determination of whether the second pixel corresponds to the at least part of the body based on determining that the angle and distance of the second pixel relative to the first pixel is below a threshold amount.

10. The system of claim **9**,

wherein the threshold amount would increase where a depth value associated with the first pixel were to decrease.

11. The system of claim **8**,

wherein the memory further bears instructions that, upon execution by the processor, cause the system at least to: determine a centroid pixel of the at least part of the body based on the first pixel and the second pixel.

12. The system of claim **11**,

wherein the memory further bears instructions that, upon execution by the processor, cause the system at least to: determine a location of a joint of the at least part of body based on the centroid pixel.

13. The system of claim **8**,

wherein the instructions that, upon execution by the processor, cause the system at least to determine that the first pixel in the depth image corresponds to the at least part of the body further cause the system at least to determine a first probability that the first pixel in the depth image corresponds to the at least part of the body, and

wherein the instructions that, upon execution by the processor, cause the system at least to determine that the second pixel in the depth image corresponds to the at least part of the body further cause the system at least to: determine that the second pixel in the depth image corresponds to the at least part of the body based on the angle and the distance of the second pixel relative to the first pixel, and the first probability.

14. The system of claim **13**,

wherein the memory further bears instructions that, upon execution by the processor, cause the system at least to:

determine that a third pixel in the depth image has a zero probability of corresponding to the at least part of the body based on the third pixel having a depth value associated with a background.

15. A computer-readable storage device that is not only a propagating signal comprising computer-executable instructions that, upon execution on a computing system, cause the computing system to perform operations comprising:

receiving a depth image that includes at least part of a body;

determining that a first pixel in the depth image corresponds to the at least part of the body; and

determining that a second pixel in the depth image corresponds to the at least part of the body based on an angle and a distance of the second pixel relative to the first pixel.

16. The computer-readable storage device of claim **15**,

wherein determining that the first pixel in the depth image corresponds to the at least part of the body comprises determining a first probability that the first pixel in the depth image corresponds to the at least part of the body, and

wherein determining that the second pixel in the depth image corresponds to the at least part of the body comprises: determining that the second pixel in the depth image corresponds to the at least part of the body based on the angle and the distance of the second pixel relative to the first pixel, and the first probability.

17. The computer-readable storage device of claim **16**, further comprising computer-executable instructions that, upon execution on a computing system, cause the computing system to perform operations comprising:

determining that a third pixel in the depth image has a zero probability of corresponding to the at least part of the body based on the third pixel having a depth value associated with a background.

18. The computer-readable storage device of claim **16**, further comprising computer-executable instructions that, upon execution on a computing system, cause the computing system to perform operations comprising:

selecting a third pixel among a plurality of pixels in the depth image for determination of whether the third pixel corresponds to the at least part of the body based on determining that the second pixel in the depth image corresponds to the at least part of the body, and based on an angle and a distance of the third pixel relative to the second pixel.

19. The computer-readable storage device of claim **16**, further comprising computer-executable instructions that, upon execution on a computing system, cause the computing system to perform operations comprising:

selecting the second pixel among a plurality of pixels in the depth image for determination of whether the second pixel corresponds to the at least part of the body based on determining that the angle and distance of the second pixel relative to the first pixel is below a threshold amount.

20. The computer-readable storage device of claim **19**, wherein the threshold amount would increase where if a depth value associated with the first pixel were to decrease.

* * * * *